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REPORT

OF

Pennsylvania Water Resources Committee

February, 1953

AND

Delaware River Basin Report

Pennsylvania Water Resources Committee

Engineers' Study Committee

January, 1953

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THE PENNSYLVANIA WATER RESOURCES COMMITTEE

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Chairman

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Secretary

REPORT OF
THE PENNSYLVANIA WATER RESOURCES COMMITTEE

To the Honorable John S. Fine, Governor of the Commonwealth of Pennsylvania.
Your Excellency:

In June, 1951, you appointed this committee and by letter outlined the tasks you were submitting to it. They were as follows:

1. To examine the Incodel Plan for the purpose of determining whether Pennsylvania, under its terms, would be in a more favorable position than it now occupies under the decree of the Supreme Court of the United States relating to the use of the waters of the Delaware River by the states of New Jersey, New York, Delaware and Pennsylvania.

2. If the committee concluded that Pennsylvania ought to become a party to the Incodel Compact, to determine whether the proposed Incodel Plan or any modification of it would adequately protect Pennsylvania's interests.

3. To make a preliminary study of the unused water supply resources of Pennsylvania for the purpose of determining to what extent southeastern Pennsylvania is dependent for its water supply upon the continued use of the waters of the Delaware River; and to make a preliminary study as to our water supply to enable you to recommend any legislation dealing with the entire subject of the conservation of Pennsylvania's invaluable water supply resources.

Within a week after the receipt of your letter, the committee organized by electing Mr. Albert M. Greenfield, Chairman, Mr. C. Jared Ingersoll, Vice-Chairman, Mr. Donald Jenks, Secretary, and, with the approval of the Attorney General, Wm. A. Schnader, Esquire, General Counsel, and George G. Chandler, Esquire, Associate General Counsel.

At this meeting, the committee also selected a sub-committee on engineering consisting of Mr. Horace Liversidge, Chairman, Mr. C. Jared Ingersoll and Admiral Draemel, then Secretary of Forests and Waters.

To the subcommittee on engineering was assigned the duty of recommending to the full committee the engineers who should be employed to do the research and make the engineering studies and recommendations necessary to enable the committee to reach its conclusions.

After several months of investigation, the subcommittee on engineering recommended, and the entire committee unanimously selected, as its engineers Messrs, Greeley and Hansen, of Chicago, Illinois; The Chester Engineers, of Pittsburgh, Pennsylvania; and Gannett Fleming Corddry & Carpenter, Inc., of Harrisburg, Pennsylvania, with which firm Mr. Charles E. Ryder is associated. These engineers will hereafter be called collectively "The Engineers' Study Committee."

By Act No. 65A of the 1951 session of the Legislature, an appropriation was made to the Department of Forests and Waters for the payment of the expenses of the committee but the appropriation was limited to expenses "necessary for the study of the water resources of the Delaware River Basin, including the Incodel Plan."

Accordingly, the committee's work up to the present moment has been confined to that part of your assignment relating to a study of the Delaware River Basin and recommendations regarding the Incodel Plan.

We shall first deal with the Incodel Plan as distinguished from the legislation already enacted by Delaware, New Jersey and New York and proposed for enactment in Pennsylvania which would

authorize the four states to enter into what is known as the Incodel Compact.

The Incodel Plan is described in a report of the Interstate Commission on the Delaware River Basin (hereinafter called "Incodel"), entitled "Report on the Utilization of the Waters of the Delaware River Basin," dated August, 1950.

It contemplates the erection of a storage reservoir on the west branch of the Delaware River at Cannonsville, New York; of a diversion dam on the main river near Barryville, New York; of a storage reservoir in New York on the lower Neversink River in Basher Kill, extending from Godeffroy to Phillipsport, New York; and of a transmission tunnel from the upper part of the Godeffroy Reservoir to New York City's existing main supply tunnels in Brooklyn. The plan states that from this common transmission tunnel, connection would be made to the large water supply systems of northern New Jersey.

This project is known as Alternate "A" of Stage I. Alternate "B" of Stage I includes all of the foregoing projects and also a storage reservoir on the main river at Wallpack Bend.

The Plan, under Stage I, contemplates supplying New York City and northeast New Jersey with 465 million gallons of water per day in addition to the 440 million gallons per day which New York City is now authorized to take by the 1931 decree of the Supreme Court of the United States.

From the water stored in the planned reservoirs and dams, it is stated that enough water would be released in times of low flow to maintain the stream flow at Trenton at 4000 cubic feet per second, if Wallpack Bend Reservoir is not constructed, and at 4800 cubic feet per second after the construction of Wallpack Bend Reservoir.

As of 1950, the estimated construction costs of the project without Wallpack Bend Reservoir were $564,154,800.

The report of Incodel states that within the next thirty years "the north New Jersey metropolitan district and the area served by New York City will need an additional 465 million gallons per day. Within a period of another 20 years (1980 to 2000) the requirements of these areas will probably increase by an equal quantity."

It is also stated that when an additional supply, above the 465 million gallons per day, is required by northeastern New Jersey and New York City it will be necessary to construct additional reservoirs. These include a storage reservoir at Fishers Eddy on the eastern branch of the Delaware, a storage reservoir in Flat Brook in New Jersey, and the Wallpack Bend Reservoir if that has not already been constructed as part of Stage I of the plan.

Thus, it is clearly the contemplation of Incodel that New York City and northern New Jersey will be permitted to take from the Delaware River in addition to the 440 million gallons daily which they are now authorized to take, an additional 930 million gallons daily or a total of 1370 million gallons per day.

It must be remembered that any water taken from the Delaware River for use by New York City or northern New Jersey is what is known as a "total diversion" as distinguished from a "partial diversion." When water is partially diverted it comes back to the same watershed at a point below the point of diversion. Thus, when Philadelphia takes water out of the Delaware River for water-supply purposes at Torresdale it returns it to the river at a lower point in the form of sewage or otherwise. When New York diverts water from the Delaware River the water never comes back to the Delaware River Basin at all. Instead, it goes into the Hudson River Basin.

The incodel Plan contemplates the making of long-term contracts for the sale of water to New York City and municipalities in northern New Jersey and the financing of the project by the issuance of revenue bonds. However, the Plan proposes that Pennsylvania should pay 35 per cent of that part of the annual costs allocated to stream flow regulation. At 1950 prices, this amount was

estimated at $1,583,350 a year without Wallpack Bend. Were Wallpack Bend constructed, the Plan would have Pennsylvania pay 39.1 per cent of the annual costs allocated to stream flow regulation which, at 1950 prices, was estimated at $2,642,250.

A mere description of the Plan renders it apparent that as far as water supply is concerned it is for the benefit of New York City and northeastern New Jersey. Only if and when the Wallpack Bend Reservoir were constructed and if and when the metropolitan Philadelphia area desired to obtain water from the integrated project and were willing and able to finance the aqueduct to carry the water from Wallpack Bend, or from an intake in the river at or near Yardley, to reservoirs and filter plants in the metropolitan Philadelphia area, could Philadelphia and southeastern Pennsylvania derive any benefit from the Plan as far as water supply is concerned.

It should also be noted that the plan contemplates the taking of prime quality water for New York and northeastern New Jersey, relegating to Pennsylvania polluted water which could not be used without filtration, and affording no assurance to Pennsylvania that during periods of protracted drought there would be sufficient water available for it.

Obviously, from Pennsylvania's standpoint, there must be some other extraordinary advantage to compensate for the total diversion of up to 1370 million gallons daily out of the Delaware River watershed, especially when the Philadelphia-South-Jersey area is seemingly on the threshold of the greatest industrial growth which it has enjoyed at any time since 1900.

The Engineers' Study Committee has considered the various advantages which Incodel asserts that the Philadelphia-south Jersey areas would derive from its plan.

These advantages are alleged to be:

1. improved sanitation;
2. salinity control;
3. protection of the oyster industry;
4. restoration of the shad fisheries; and
5. improved facilities for recreation.

In summary, the Engineers' Study Committee finds that:

1. Respecting sanitation the overall effect of low flow augmentation would be slight. It might be helpful in the immediate vicinity of sewage discharges into the upper reaches of the river, but in general it would be harmful to present public water supplies taken from the river. In the critically polluted estuary its effect would be insignificant. An improved sanitary condition of the river can better be obtained by the treatment of sewage and industrial wastes to at least the degree now proposed and probably to a higher degree in the future.

2. The amount of low flow augmentation obtainable from the Incodel Plan would not eliminate the frequent and increasing salinity invasions in the Chester-Marcus Hook area.

3. The oyster industry is of no real importance to Pennsylvania, but the limited investigations of the Engineers' Study Committee indicated that the Incodel project would not appreciably help that industry.

4. So far as concerns shad fishing, the primary cause of the decline in this industry is the pollution of the estuary. Since flow augmentation cannot materially reduce that pollution it cannot appreciably benefit the shad fishing industry. The cure is better sewage and industrial waste treatment.

5. As regards recreation, reservoirs constructed in New York would not be of material

benefit to Pennsylvania because of their remoteness from centers of population within Pennsylvania and because of the high fees charged by New York for non-resident fishing licenses.

After the most careful consideration of the report of the Engineers' Study Committee, their reasons and the data upon which the reasons are based, your committee unanimously endorses their findings.

Thus, it appears that there would be no such important benefits derived by Pennsylvania from the low flow augmentation proposed by Incodel as to compensate for the total diversion of an additional 930 million gallons daily from the Delaware River watershed.

It follows as a necessary conclusion that Pennsylvania would not be justified in bearing any of the cost of the construction or maintenance of reservoirs and dams in New York intended to supplement the present water supply of New York City and northeastern New Jersey.

The one remaining question is whether if the Incodel project were constructed without cost to Pennsylvania, Pennsylvania should consent to the total diversion of up to 1370 million gallons daily from the Delaware River watershed.

The conclusion of the Engineers' Study Committee is that such relatively large diversions may result in long-range effects which cannot be predicted with assurance, and therefore, should not be countenanced.

With this conclusion also your Committee agrees unanimously.

So much for the Incodel Plan.

Now we shall discuss the proposed reciprocal legislation proposed between Delaware, New Jersey, New York and Pennsylvania. The purpose of the legislation is to authorize the execution of a Compact among the four states.

The act has been passed by Delaware and New Jersey substantially as proposed by Incodel, but by New York with very important deviations.

Under the bill proposed by Incodel there would be no possible way for any state, once it had executed the Compact, subsequently to withdraw from it. Therefore, the Compact would run on in perpetuity, unless all four states unanimously agreed to rescind it.

This it seems to us is in itself a fatal objection to the Compact. We do not believe that the present members of Incodel, or any other representatives of the four states are sufficiently wise and prophetic to write a Compact now which will take into account every condition which may arise in the future.

Some proponents of Incodel make the statement that the proposed Compact does not make any allocations of the waters of the Delaware to New York and New Jersey, but that these allocations would be entirely in the discretion of the Commission which the Compact would create. That Commission would consist of three representatives from each state appointed by the Governor in the usual manner in which gubernatorial appointments are made in the particular state.

We pause to point out that the Compact itself specifies with particularity the dams, reservoirs and conduits which are to be constructed as the initial stage of the project. All of these dams, reservoirs and conduits are intended primarily to augment the present water supply of New York City and northeastern New Jersey.

Accordingly if the Commission were established in order to construct the project on a revenue bond basis, long term water contracts must necessarily be executed before the financing can be accomplished. Thus to make possible the financing, the Commission would be bound to allocate to

New York and northeastern New Jersey the quantities of water which the Plan envisages.

If this allocation were not made, then the compact would be nothing but a useless scrap of paper, as nothing practical could possibly result from its execution.

However, the Compact as proposed by Incodel provides in Article III, paragraph 2 that no action of the Commission concerning any allocation of water for water supply shall be binding unless a majority of the commissioners from each of the signatory states shall have voted in favor thereof. Under that proposal two of the three representatives from any one state could block any proposal to make an allocation of water to Pennsylvania. However, the New York act goes still further and provides in the same Article and paragraph that no allocation of water for water supply *or for the maintenance of an adequate minimum flow to any signatory state or any political subdivision therein* shall be binding unless the majority of the members from each state shall have voted in favor of it *and unless the Governor of the state shall have had an opportunity to approve or veto the same.*

Therefore if at some future date Pennsylvania should desire an allocation of water, or if at some future date it was found that the diversion to the Hudson water shed of water from the New York reservoirs required additional releases for any reason, the Governor of New York, or the Governor of New Jersey, or the Governor of Delaware, by vetoing Pennsylvania's request could prevent the allocation or the increased augmentation releases.

Such an arrangement is unthinkable, especially as Philadelphia and southeastern Pennsylvania have not as yet reached definite conclusions as to the point or points in the upper Delaware basin at which they will seek their future water supplies. And because of the great increase of industrial activity in the Morrisville-Trenton area, it is virtually certain that water supply will have to be obtained from upland sources at sometime in the future.

Finally, Article IX, paragraph 1 of the Compact would provide that "no signatory state shall permit the flow in the Delaware River to be diminished by the Diversion of any water from the main channel of the Delaware River during any period in which waters are being released from storage reservoirs constructed under the provisions of this Compact for the purpose of maintaining an adequate minimum flow in the Delaware River during periods of low flow therein, except in cases where such diversion shall have been duly authorized under the provisions of this Compact."

This provision, like the one previously discussed, would place Philadelphia and southeastern Pennsylvania at the mercy of any one of the other three states if it sought to obtain its water supply from the main channel of the Delaware River above Trenton. It would practically force Philadelphia, if and when upland sources of water are required, to construct its dams and reservoirs within Pennsylvania on tributaries of the Delaware, or on other streams in proximity thereto.

Certainly Pennsylvania should not enter into any Compact in which it agrees to let any other state be the final arbiter of its right to its fair share of the waters of the Delaware.

Pennsylvania is in a far more favorable position under the 1931 decree of the Supreme Court of the United States in the case of NEW JERSEY v. NEW YORK, et al., 283 U.S. 336 (1931).

Under the decision of the Supreme Court directing that decree to be entered, it was held that New Jersey, New York and Pennsylvania are each entitled to a fair and equitable share of the waters of the Delaware and that New York's share would not exceed 440 million gallons per day. The decision rested on the finding of a special master that the total diversion by New York of more than 440 million gallons per day would do substantial damage to New Jersey and Pennsylvania.

New York City is now seeking to have the Supreme Court of the United States modify its decree to the extent of permitting that city to divert 360 million gallons per day over and above the 440 million gallons per day already permitted. We understand that Pennsylvania is vigorously resisting this attempt.

In any event, we are satisfied that Pennsylvania will be better off if it continues to permit the Supreme Court of the United States finally to decide upon the facts as they then exist, what the fair and equitable shares of the several states are, than it could possibly be by becoming party to a Compact under which its reasonable requests could be denied by the arbitrary whims of the representatives of any one of three other states.

Counsel advise us that there is a serious question whether the proposed Compact would not be an unconstitutional delegation of legislative power in that no standards whatever are established by law for determining what the shares of the several states shall be in the waters of the Delaware. The Compact would authorize the Commission to allocate to each state its "equitable share" of the water without any yardstick by which that share should be measured.

For all of the foregoing reasons, your Committee recommends that Pennsylvania should not become a party to the Incodel Compact.

One question remains. If Wallpack Bend reservoir is not constructed as a part of the Incodel project, and when Philadelphia and southeastern Pennsylvania will in the future find it necessary to go upland for their water supplies, where can they go?

The report of our Engineers' Study Committee answers that question definitely and satisfactorily. Several alternatives are presented.

One of them is the construction of the Wallpack Bend reservoir by agreement between Pennsylvania and New Jersey. It is obvious that New York's interest in the Delaware River Valley ceases at the New York state line at Tri-state Rock and that the use of the Delaware River and its tributaries below that point is almost exclusively the concern of New Jersey and Pennsylvania. Certainly, unless Delaware at some future date desires to obtain a part of its water supply from reservoirs built in Pennsylvania or New Jersey, or on the main channel of the Delaware above the Delaware state line, it has no interest at all in a partial diversion of the waters of the Delaware which would return the diverted water into the Delaware above the Delaware state line.

Our Engineers' Study Committee has also outlined five additional projects, — four in Pennsylvania and one in New Jersey, — which, either in conjunction with the Wallpack Bend Reservoir or without it, could accommodate the water supply needs of the greater Philadelphia area and supplement the present water supply of southern New Jersey during the foreseeable future.

The Pennsylvania projects are described in the engineers' report as the Lehigh-Nescopeck Project, the Lehigh-Tobyhanna Project, the McMichaels-Pocono Project, and the Pohopoco Project. The New Jersey project is the Flat Brook Dam, which is also described in the engineers' report.

In addition, Pennsylvania's engineers, who testified in the Delaware River Diversion case in 1930, pointed out that other reservoir sites on Bushkill and Brodheads Creeks and on the Lackawaxen River and Shohola Creek, within Pennsylvania, have a potential yield which would be sufficient to bring the total yield of reservoirs entirely within Pennsylvania to 900 million gallons per day. Water from reservoirs on all of these streams could either be carried by aqueduct directly to the Philadelphia metropolitan area or to the main channel of the Delaware River where it would be available to supply intakes at or near Yardley.

New Jersey may very well desire to cooperate with Pennsylvania in the development of all or some of these projects on a fair basis, and, because certain of these projects would, in addition to furnishing water supplies, provide flood control for the Lehigh Valley, the United States government would probably contribute to the cost.

If New Jersey declines to cooperate with Pennsylvania in these developments, Pennsylvania can alone construct a combined project of dams and reservoirs at a cost probably no greater than its

share of the cost of the Incodel project. And, if the quantity of water diverted does not exceed Pennsylvania's fair and equitable share, and if provision is made for appropriate releases of water at times of low flow, we do not see how any other state could complain.

You have asked us to suggest legislation which you may wish to recommend to the Legislature.

It would seem to be an act of foresight for Pennsylvania to establish a state water authority with jurisdiction to investigate and conserve all of Pennsylvania's invaluable unused water resources.

Such an authority should have the duty to make studies of the other important watersheds in Pennsylvania comparable with those which our Committee has made of the Delaware River Basin. It should have power to designate as "Class A" any streams anywhere in Pennsylvania which are available for water supply purposes and to publicize such action. The legislation should contain appropriate standards which would govern the authority's action in designating any stream a "Class A" stream.

The authority should also be given power to propose projects for water conservation and supply and for flood control wherever in Pennsylvania there are water resources which our citizens may require for their present or future needs.

Your Committee believes that our State's invaluable unused water resources should be conserved so as to be available when expanding urban populations and industrial growths require additional quantities of water and when, as surely will be the case, thickly populated areas will insist upon upland sources of water supply.

Specifically, with regard to the Delaware River Valley problem, such an authority should have power:

a. To negotiate with New Jersey to ascertain whether it wishes to cooperate with Pennsylvania in any of the projects we have mentioned;

b. To make estimates of the costs of acquiring the land and the water rights, if any, involved in these projects and constructing them;

c. To explore the question whether any political subdivision in southeastern Pennsylvania is presently interested in making long-term contracts for the purchase of water from the authority;

d. To adopt an over-all plan for supplying the water supply needs of southeastern Pennsylvania during the foreseeable future; and

e. To acquire the land and water rights, if any, necessary for the construction of the planned projects by the exercise of the power of eminent domain or otherwise.

Necessarily, any power given to the authority must be delimited by appropriate standards.

It should be pointed out that the longer the acquisition of land for these projects is delayed the more costly that acquisition will be. Even in the areas surrounding the upland sources, until the State at least gives notice that it will require land for water supply projects, building and development will continue to go on.

Our engineers have convincingly demonstrated that the needs of the Philadelphia metropolitan area for water from the Delaware River and its tributaries by the end of this century will be 900 million gallons per day. The withdrawal of this quantity of water from the Delaware and Schuylkill Rivers cannot possibly be maintained throughout the year without dams and reservoirs upstream from Morrisville-Trenton.

Our engineers have shown that a satisfactory water supply could be delivered to the Philadelphia metropolitan area either directly or, — more cheaply, — by pouring the water from the dams

and reservoirs into the main stream of the Delaware River and taking it out for water supply at Yardley.

Which of these alternatives should be adopted would be for the water authority, in conjunction with the municipalities to be supplied, to work out.

We stand ready to make any further studies which you may require of us.

Respectfully submitted,

/s/
Albert M. Greenfield
Chairman

/s/
Thomas Buckley

/s/
C. Jared Ingersoll

/s/
Samuel S. Lewis

/s/
Horace P. Liversidge

/s/
William D. Mason

/s/
Frederic A. Potts

/s/
Casimir A. Sienkiewicz

/s/
Andrew J. Sordoni

Friday, February 6, 1953

REPORT ON THE DELAWARE RIVER BASIN

BY

The Engineers' Study Committee

The Chester Engineers
Gannett, Fleming, Corddry & Carpenter, Inc.
Greeley and Hansen

TO

Pennsylvania Water Resources Committee

GOVERNOR JOHN S. FINE

ALBERT M. GREENFIELD
Chairman

THOMAS BUCKLEY
C. JARED INGERSOLL
SAMUEL S. LEWIS
HORACE P. LIVERSIDGE
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WILLIAM A. SCHNADER
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GEORGE G. CHANDLER
Associate General Counsel

DONALD JENKS
Secretary

January, 1953

COMMONWEALTH OF PENNSYLVANIA

WATER RESOURCES COMMITTEE

REPORT ON THE DELAWARE RIVER BASIN

by its

ENGINEERS' STUDY COMMITTEE

THE CHESTER ENGINEERS
GANNETT, FLEMING, CORDDRY & CARPENTER, INC.
GREELEY AND HANSEN

JANUARY, 1953

1. Foreword

The purpose of this report is to present the results of investigations and studies relating to the use, development and control of the Delaware River Basin and of its major tributaries within the boundaries of the Commonwealth.

The Engineers' Study Committee has been guided in its investigations by the instructions contained in the agreement with the Commonwealth dated February 1, 1952, as follow:

A. To make such engineering studies and surveys of the water resources of this Commonwealth, the water needs of its inhabitants, and the best ways and means of meeting and serving the same as the Committee may from time to time order and direct in order to carry on its study of the water resources of the Delaware River Basin, including the Incodel Plan.

B. To conduct such investigations, render such reports and opinions, and make such recommendations respecting their engineering studies and surveys as are necessary and appropriate.

C. To consult with and advise the Committee in regard to their investigations, studies and surveys, the results thereof, and their recommendations and opinions thereon.

D. To prepare and submit to the Committee for examination and approval such outline plans and drawings with supporting engineering records, data, and estimates of cost as are necessary to complete their investigations, studies and surveys.

2. Findings

In accordance with our instructions, we have studied the ways and means of meeting and serving the water needs of the Pennsylvania inhabitants of the Delaware River Basin, including the Incodel Plan. Our findings indicate that Pennsylvania has no essential need for the Incodel Plan.

The Incodel program calls for the construction of dams, reservoirs, conduits, and control works to furnish the following:

1. Water Supply to New York, New Jersey, Pennsylvania, and Delaware.
2. Low flow augmentation to meet five so-called immediate needs of the river, as follows:

   Sanitation
   Salinity Control
   Protection of Oyster Industry
   Restoration of Shad Fishery
   Recreation

Northern New Jersey and the New York City area would be the principal beneficiaries of the

water supply features of the Incodel project. In fact, Stage One, Alternate A, of the project includes no provisions for water supply for Pennsylvania. However, 7 per cent of its cost, amounting to upwards of $46,000,000, would be assessed to the Commonwealth.

As regards the five "immediate needs for low flow augmentation," we find as follows:

(a) Sanitation

Respecting sanitation, the overall effect of low flow augmentation would be slight. It might be helpful in the immediate vicinity of sewage discharges into the upper reaches of the river. But, in general, it would be harmful to present public water supplies taken from the river. In the critically polluted estuary, its effect would be insignificant. An improved sanitary condition of the river can better be obtained by the treatment of sewage and industrial wastes to the degree now proposed. A still higher degree of treatment may be justified in the future.

(b) Salinity

The amount of low flow augmentation obtainable from the Incodel Plan will not eliminate the frequent and increasingly severe salinity invasions in the Chester-Marcus Hook area.

(c) The Oyster Industry

The oyster industry is of no real importance to Pennsylvania. Our present somewhat limited investigations do not clearly demonstrate that the Incodel project would appreciably help that industry. The U. S. Fish and Wildlife Service has just recently initiated a detailed study of conditions in Delaware Bay and in the estuary below the Delaware-Pennsylvania boundary to determine what effect, if any, low flow augmentation would have upon shellfish propagation.

(d) Commercial Fishing

As far as Pennsylvania is concerned, the principal value of commercial fishing is in the shad fishery. The primary cause of the decline in this industry is the pollution of the estuary. Since flow augmentation cannot materially reduce that pollution, it cannot appreciably benefit the shad fishery. If it is desired to revive the shad fishery in the Delaware River, it may best be done by providing sewage and industrial waste treatment to at least the degree now proposed. Future conditions may demonstrate that additional treatment is required.

(e) Recreation

As regards recreation, it is our opinion that reservoirs constructed in New York will not be of material benefit to Pennsylvania since their remoteness from centers of population within the Commonwealth and the present fees charged for non-resident fishing licenses constitute barriers to their use.

Wallpack Bend appears to be the most practical reservoir site on the main river channel below the New York State line. It has frequently been considered as a source for Philadelphia's future water supply. Construction of Wallpack Bend Reservoir would require the cooperation of New Jersey and probably the allocation of a portion of its yield to that state. That reservoir alone would not have sufficient storage to supply the ultimate needs of Pennsylvania and southern New Jersey for upland water under present river conditions.

There are sites on tributaries of the Delaware River, wholly within Pennsylvania, for dams and reservoirs to provide for water supply or low flow augmentation. Such projects could supplement the Wallpack Bend Reservoir, although we find no immediate need for their construction.

Our study shows that certain important natural conditions are changing and that certain man-made conditions also are in process of changing. The implications of these changes for the people of Pennsylvania are difficult to predict, but they are suggestive of important future consequences.

Among these changes are the following:

(a) The rising elevation of the Atlantic Ocean and of the estuary.

(b) The increasing tidal range at Philadelphia.

(c) The increasing degree of sewage treatment now under way and scheduled for completion in 1955.

(d) The expected industrial developments and increase of population stimulated by the Fairless Works and other industries.

(e) The recent petition to the Supreme Court by New York for an increased complete diversion of 360 m.g.d.

(f) The effect of metering and water waste reduction programs under way in Philadelphia and New York.

(g) Further dredging of the river channel.

In addition to the 440 m.g.d. already authorized by the Supreme Court, under Stage 1 of the Incodel Plan, up to 465 m.g.d. would be diverted out of the Basin to northern New Jersey and the New York City area and later, under the plan, up to 930 m.g.d., making a total of 1,370 m.g.d. Such

relatively large diversions may result in long range effects which cannot be predicted with assurance and, therefore, should not be countenanced.

Pennsylvania can in the future meet the water supply needs of its inhabitants by reservoirs in Pennsylvania on tributaries of the Delaware or by reservoirs on the Delaware River between Pennsylvania and New Jersey, provided that the point of withdrawal is at or near Yardley. While there is no present definite plan for financing and constructing such upland water supplies from the Delaware River, no works should be undertaken which would in any way interfere with their future accomplishment.

Figure 1 is a map of the Delaware River Basin. Fifty and three tenths per cent (50.3%) of its area is in Pennsylvania.

3. Description of the Engineers' Studies and Report

The investigations of the Engineers' Study Committee have required the collection, organization, and review of a great deal of general information and basic data.

Many existing reports, documents, and records have been studied. These are listed later as references and sources of information. Among them are the Incodel Reports and records, the records and reports of the Corps of Engineers, U. S. Army, and data relating to the water supplies of Philadelphia and of New York City. In addition to studying such existing data, independent investigations in the field and by office studies of certain phases of the problem have been made by the Engineers' Study Committee. This is particularly true of salinity control, pollution control, and certain reservoir projects on tributaries of the Delaware River.

The paragraphs and sections immediately following describe the various matters affecting the interests of Pennsylvania in the Delaware River. Since the Delaware River is an interstate stream, the more important interstate actions affecting it are first stated, after which Pennsylvania's various interests in, and needs from, the Delaware River, with procedures for protecting and satisfying those interests and needs, are described.

4. Review of Interstate Cooperation

The desirability of providing a strong cooperative supervision of the use and development of the Delaware River has been recognized by the abutting states since 1923. Pennsylvania in 1930 stated its position in its petition to the U. S. Supreme Court for the appointment of a river master to administer the Pennsylvania plan of impounding and release.

Each of the abutting states has executive and administrative departments, boards, commissions, and officers to whom have been assigned the power to regulate and control the use and abuse of intrastate streams in the Delaware River Basin. However, none of those departments, boards, commissions or officers have any authority outside of their own state and, therefore, none of them can adequately regulate the use of the river. In 1923, the governors of New York, New Jersey, and Pennsylvania, under authority of their respective legislatures, appointed commissioners who prepared a form of interstate compact which was submitted for approval to the three state legislatures in 1925.

The proposed compact described the order of importance and the public value of the uses of the Delaware River Basin. It set up rules to govern both partial and complete diversions of such waters and the release of stored water to compensate for such diversions. It also provided for the creation of a tri-state Delaware River Commission which would have the authority to pass upon and to grant or refuse all applications for developments on the river or its tributaries, and to regulate and administer the construction and operation of such developments to the extent necessary to insure compliance with the rules and regulations of the compact. However, the commission did not itself have the right to finance, construct, or operate river development projects.

The right to build dams and other regulating works was reserved to each of the signatory states acting either alone or together. However, in the event of conflict between applications from various states, the commission had the power to decide between the applications on the basis of the rules and regulations set forth in the compact. Since the compact did not allocate or divide the waters of the Delaware River Basin between the three states, the right to make such allocations evolved to the commission.

This compact was approved by the New York legislature but failed of passage in the legislatures of New Jersey and Pennsylvania. Despite the failure to adopt the 1925 compact, the need for a regulatory body to administer Delaware River Basin affairs was still apparent.

The commissioners of the three states prepared a second compact plan of a less comprehensive nature which was presented to the legislatures in 1927. The 1927 compact was designed to safeguard the river and at the same time to enable each of the three states to make use of part of its waters for the purpose of meeting present and reasonable future needs. Allocations for water

diversions were made to each of the states as follows:

State	*Allocation in m.g.d.*
Pennsylvania	900
New Jersey	600
New York	600
Total	2,100

As before, rules were set up for controlling the compensating releases to be made for such diversions. Again, a commission was proposed to administer the rules and regulations of the compact.

Like the 1925 compact, this proposal also failed to be approved by the three legislatures. At that time New York City was extremely anxious to utilize waters of the upper Delaware River, and, since it seemed apparent that no interstate agreement would be reached, the City proceeded with preliminary plans for constructing the necessary dams and diversion works.

In May, 1929, New Jersey filed with the Supreme Court of the United States a bill of complaint against the State of New York and the City of New York, opposing such diversions. The bill was answered by the defendants, and the Commonwealth of Pennsylvania was permitted to intervene. The Supreme Court appointed a Special Master to hear testimony.

After extensive hearings, the Master recommended that New York be enjoined from diverting more than 440 m.g.d. and that this diversion be subject to certain specified conditions. The Supreme Court sustained the Special Master, but stipulated that the case should be retained in the Court, and provided that appropriate applications for relief might thereafter be made by any party to the original case. Thus, since 1930, the United States Supreme Court has retained jurisdiction over the interstate use of the Delaware River, and, as of today, no project for water diversion can be consummated without the Court's approval. While such an arrangement assures a fair use and development of the river, it prevents further water diversions without litigation before or application to the Court.

The Court in 1930, did not see fit to appoint a River Master to study the use of the river or administer its decree, despite the fact that Pennsylvania petitioned the Court to make such an appointment. Obviously the states could not appoint an administering commission. However, they did feel that a commission was needed at least to study all phases of the future use and development of the Delaware River Basin waters. Therefore, in 1936, New York, New Jersey, Delaware, and Pennsylvania created the present Interstate Commission on the Delaware River Basin (Incodel).

Since then, Incodel has conducted numerous worth-while studies of the river and its basin problems. However, it has been handicapped by its limited legislative authority. It could only recommend as to and not regulate the use of the river. To be effective, each of its recommendations had to be approved by the legislatures of all four states. This often entailed much delay. For example, in 1938 Incodel proposed rules to correct and control stream pollution within the Basin, and these rules were approved by the four State Health Departments. However, they could not become effective until the legislatures of the four states had passed acts supporting such rules. The Pennsylvania law was not enacted until April, 1945. Other recommendations made by Incodel are either pending before one or more of the state legislatures, or have failed to obtain unanimous approval of those legislatures.

5. Pennsylvania 1930 Plan of Release

In the case before the Supreme Court of the United States designated as No. 16 Original in the October Term of 1930, the Commonwealth presented a so-called Pennsylvania Plan. This Plan of release, developed by Mr. Charles E. Ryder, was divided into two parts, the first governing diversions from tributaries of the Delaware River above Port Jervis and the second governing diversions from tributaries between Port Jervis and Trenton. The Plan is described in the Brief for the Commonwealth by Mr. William A. Schnader and Mr. George C. Chandler, as follows:

> *"In that part of the Delaware River above Port Jervis, water may be impounded on tributaries for diversion whenever the flow of the Delaware River at both Port Jervis and Trenton exceeds 0.5 c.s.m. Whenever the flow at Port Jervis or Trenton falls below 0.5 c.s.m., then so much water shall be released from the impounding reservoirs as will maintain this flow at 0.5 c.s.m., provided that the required rate of such release shall not exceed 30 per cent. of the average run-off rate for the period of record on the controlled area from which the release is made" (R. 3466-67).*
>
> *"In that part of the Delaware drainage basin tributary to the Delaware River between Port Jervis and Trenton, water may be impounded on tributaries for diversion whenever the flow of the Delaware River at Trenton exceeds 0.5 c.s.m. Whenever the flow at Trenton falls below 0.5 c.s.m., then so much water shall be released from the impounding reservoirs as will maintain this flow at 0.5 c.s.m., provided that the required rate of such release shall not exceed 30 per cent. of the average run-off rate for the period of record on the controlled area from which the release is made" (R. 3466-67).*

The Special Master in his report to the Court approved the Pennsylvania Plan of releasing water from the impounding reservoirs "for the

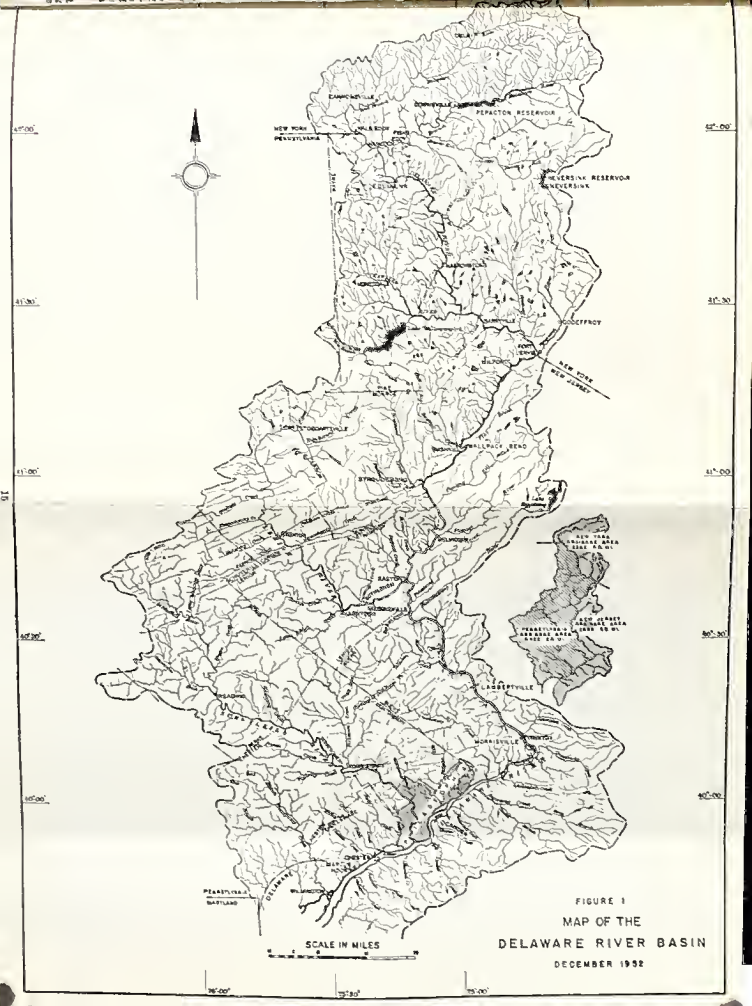
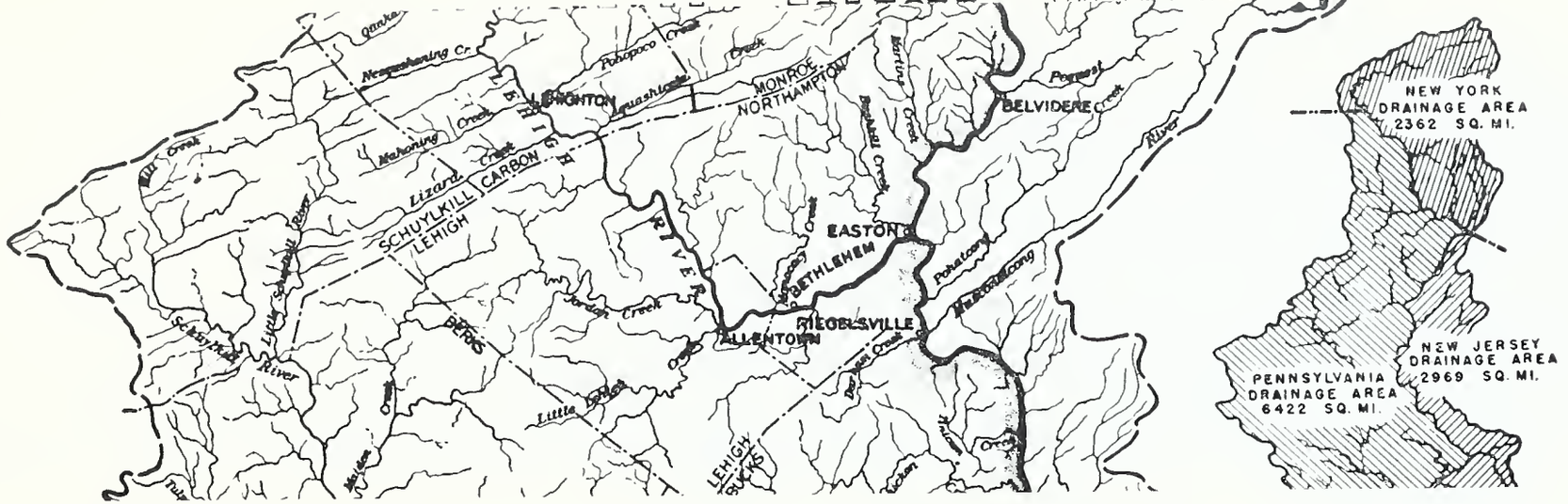


FIGURE 1

MAP OF THE

DELAWARE RIVER BASIN

DECEMBER 1952


Gunko
Nesquehoning Cr.
Pohopoco Creek
Aquashicola Creek
MONROE
NORTHAMPTON
BRIGHTON
Mahoning Creek
Lizard Creek
CARBON
SCHUYLKILL
LEHIGH
Beltzville Creek
Pohopoco Creek
Bushkill Creek
Bertins Creek
Pomeroy
BELVIDERE
Delaware River
EASTON
BETHLEHEM
Monocacy Creek
Hokendauqua Creek
RIEGELSVILLE
ALLENTOWN
Jordan Creek
Schaefferstown
Little Swatara River
BERKS
Little Lehigh
Manatawny Creek
Perkiomen Creek
Tohickon Creek
LEHIGH
BUCKS
NEW YORK
DRAINAGE AREA
2362 SQ. MI.
NEW JERSEY
DRAINAGE AREA
2969 SQ. MI.
PENNSYLVANIA
DRAINAGE AREA
6422 SQ. MI.

40°-30'

40°-30'

present, subject to such modifications as actual tests and experience may indicate, and without prejudice to any party to this case to apply for modification." The Pennsylvania Plan appears in the decree of the Supreme Court dated May 25, 1931, as follows:

"At any time the stage of the Delaware River falls below .50 c.s.m. at Port Jervis, New York, or Trenton, New Jersey, or both (.50 c.s.m. being equivalent to a flow of 1,535 c.f.s. at Port Jervis and 3,400 c.f.s. at Trenton), water shall be released from one or more of the impounding reservoirs of New York City in sufficient volume to restore the flow at Port Jervis and Trenton to .50 c.s.m., provided, however, that there is not required to be released at any time water in excess of 30% of the diversion area yield, and the diversion area yield having been ascertained to be 2.2 c.s.m., the maximum release required shall be 30% of that amount, or .66 cubic feet per second per square mile of the areas from which water is diverted."

There has, of course, been no opportunity to judge the effect of the Pennsylvania Plan, as the reservoirs under construction by New York City are only now being completed.

Some years of low flow in the Delaware River after the application of the release plan will be required to fully ascertain its competence. In other release formulae (see Section 25), some changes have been proposed to make the actual release of water a more practical operation in connection with the river flows at Trenton and the changes therein from day to day and from week to week.

The prayer of the Commonwealth of Pennsylvania for the appointment of a River Master was denied without prejudice.

6. New York City Diversions

The New York City plan for diverting water from the upper Delaware River Basin is shown on Figure 2. It comprises, at present, dams and reservoirs on the east branch of the Delaware River at Downsville (the Pepacton project) and on Neversink Creek at Neversink, to divert 440 m.g.d. with compensation releases therefor in accordance with the order of the United States Supreme Court. These works are about to start operation. New York City has recently petitioned the Supreme Court for the right to divert an additional 360 m.g.d. by the construction of the so-called Cannonsville project on the west branch of the Delaware River.

7. The Incodel Plan

The Incodel Plan is shown on Figure 3, taken from the Report of August, 1950. It comprises dams, reservoirs, conduits, and control works to provide water for northern New Jersey, the New York City area and, later, for Philadelphia, southeastern Pennsylvania, and the Metropolitan district of southern New Jersey; and, in addition, low flow augmentation to maintain a minimum flow at Trenton, first of 4,000 c.f.s. and later of 4,800 c.f.s. Stage 1, Alternate A was estimated to cost $586,000,000 in 1950 and would cost $700,000,000 or more if built during the next few years.

In support of the project, it is stated in the Incodel Report that there is immediate need for water supply and for stream flow regulation. For the most part, and certainly for the first stage of the project, the water to be supplied is limited to northern New Jersey and the New York City area. As measured by cost, about eighty per cent of the project is for water supply works. The things that are said to cause the immediate need for stream flow regulation are briefly summarized as follow:

a. Improvement in Sanitary conditions in the lower river.

b. Improvement in Salinity conditions in the lower river.

c. Prevention of the destruction of young oysters.

d. Acceleration of the program for the restoration of the shad fisheries.

e. Recreational needs.

The foregoing items are discussed in later sections of this report.

8. Enabling Legislation Suggested by Incodel

The Incodel Report of August, 1950, suggests a legislative program which is described as a compact between the four states to accomplish an integrated water project in the Delaware River Basin. The compact, it is stated, should "cover the creation of an Authority or Commission for joint action between the states for the development, utilization, control and conservation of the water resources of the . . . Basin" for the purpose of

(a) Assuring adequate water supplies.

(b) Providing an adequate minimum flow.

(c) Improving sanitary conditions.

(d) Arresting salinity incursions.

(e) Providing for other usages and controls of water, such as navigation, flood control, power, and other related purposes.

The Commission, it is stated, would have power to plan, finance, construct, operate and maintain facilities, such as dams, reservoirs, and other appurtenant structures within the Basin above Trenton.

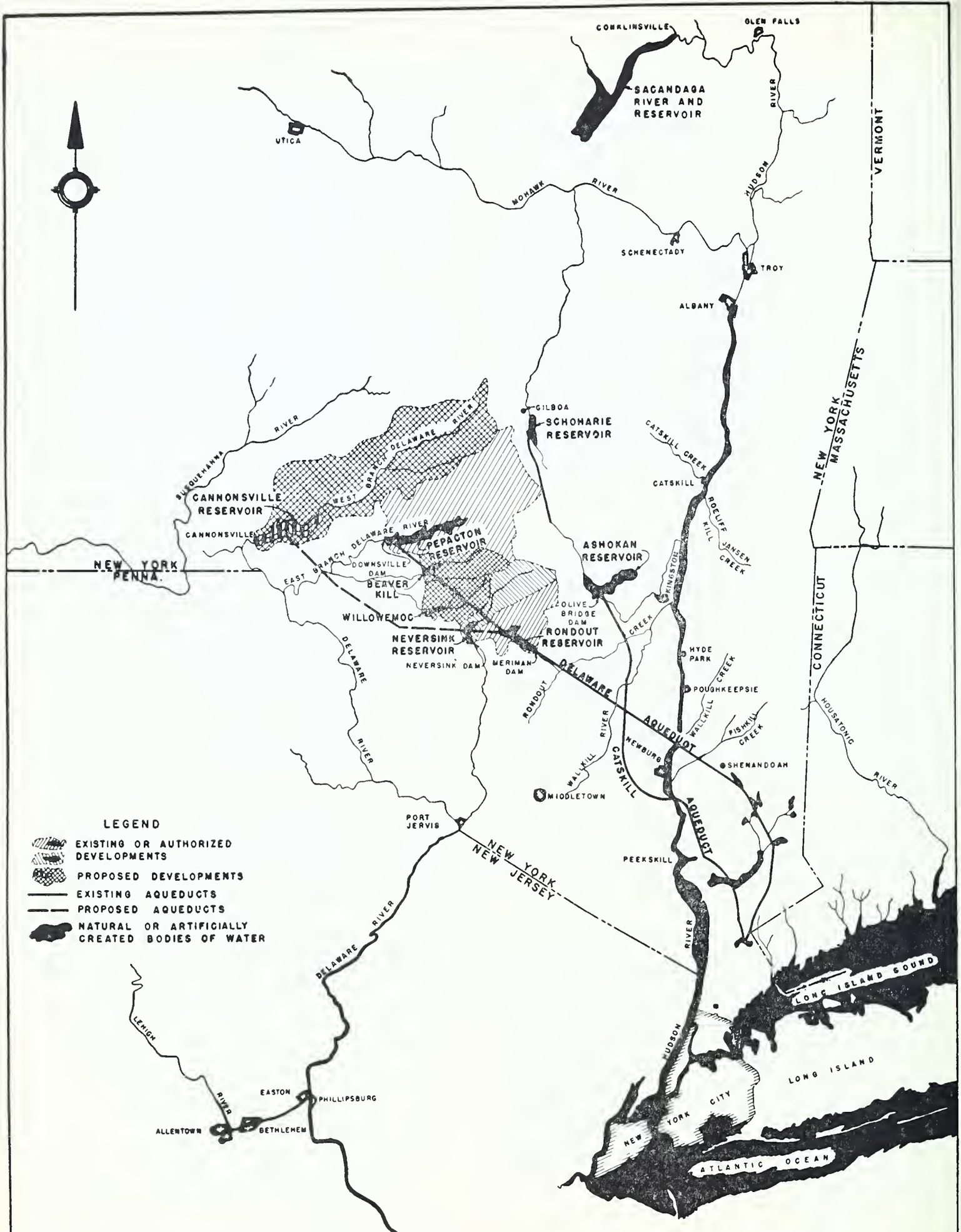


FIGURE 2

PROPOSED NEW YORK CITY DIVERSIONS FROM DELAWARE RIVER

DECEMBER 1952

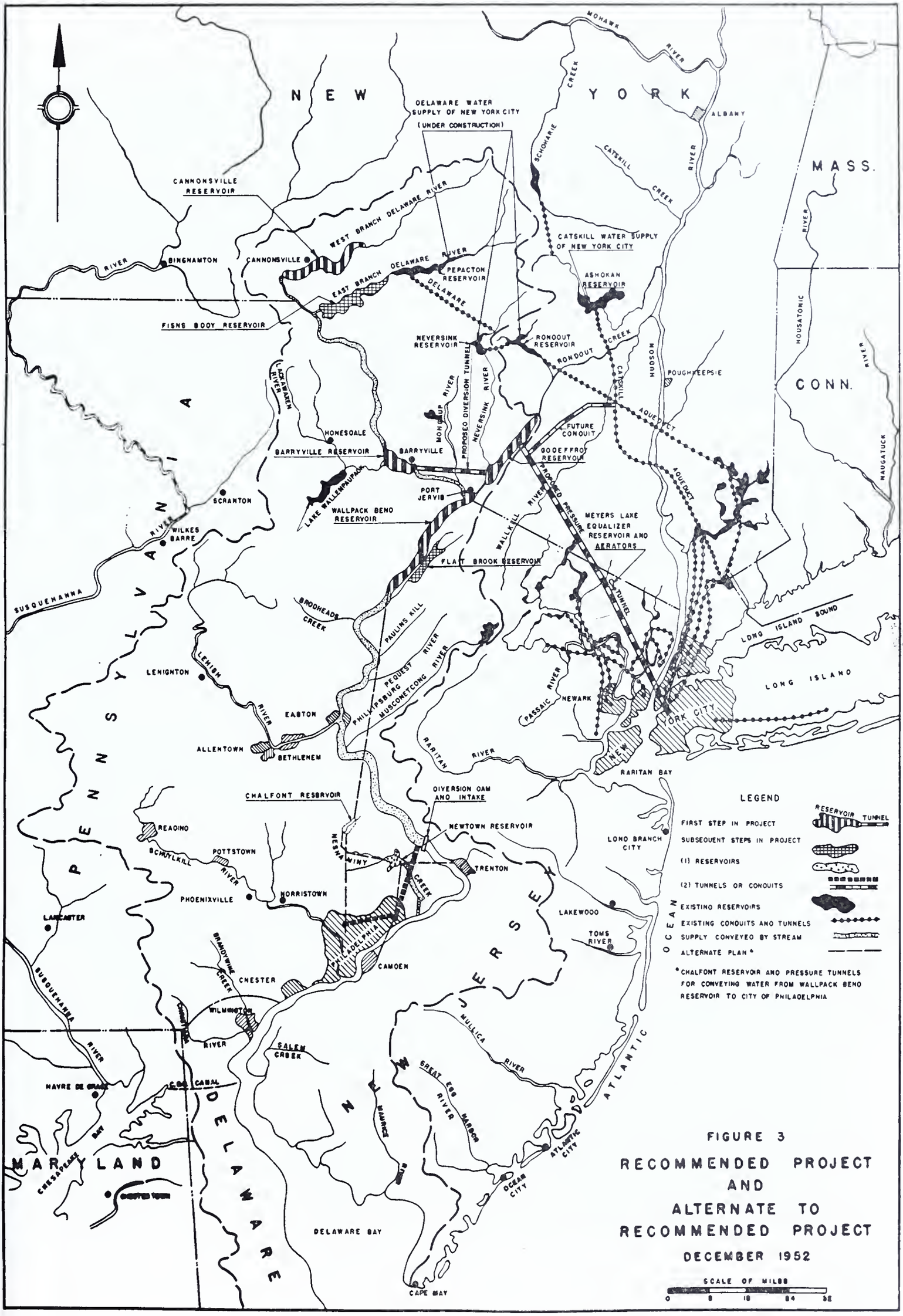


FIGURE 3

RECOMMENDED PROJECT AND ALTERNATE TO RECOMMENDED PROJECT

DECEMBER 1952

The suggested Commission would also have the foregoing powers as regards facilities to transport and treat water.

To carry out the proposed work, the joint Commission would need certain powers, as follow:

(1) To acquire property

(2) To exercise eminent domain

(3) To borrow money

(4) To collect "rentals" for the use of its facilities

(5) To engage engineers

(6) To allocate to each state an "equitable apportionment of available water supply."

(7) To determine the quantities of release water

(8) To provide for a means of utilizing and controlling the water resources of the Delaware River Basin in cooperation with other state agencies for such purposes as navigation, flood control, production of hydroelectric power and other related uses.

(9) To provide for the development of hydroelectric power

(10) To enter into contracts for the sale of water.

Pursuant to this suggestion, Acts have been presented by Incodel, and have been passed by the legislatures of New York, New Jersey and Delaware, and one has been suggested for Pennsylvania. The integrated water project described in the legislation is outlined as follow:

(a) A dam across the West Branch of the Delaware River near Cannonsville, New York

(b) A dam across the Delaware River near Barryville, New York

(c) A dam across the Neversink River near Godeffroy, New York

(d) A dam across the Delaware River near Wallpack Bend

(e) A dam across the East Branch of the Delaware River near Fishs Eddy

(f) A dam across Flat Brook near Flatbrookville, New Jersey

(g) An aqueduct connecting the reservoir created by the dam across the Delaware River near Barryville, New York, with the reservoir on the Neversink River created by a dam near Godeffroy, New York

(h) An aqueduct, with equalizing reservoir en route, to convey a supply of water from the reservoir on the Neversink River created by the dam near Godeffroy, New York, to political subdivisions in northern New Jersey and to the City of New York

(i) Such dams, reservoirs, tunnels, conduits, and other facilities as may be required to furnish water supply to the City of Philadelphia or other political subdivisions and metropolitan areas in the greater Philadelphia-south Jersey area situated wholly within the Delaware River Basin.

The foregoing mandatory project is subject to paragraph 1 of Article XV, as follows: "Nothing in this compact shall be construed as impairing the powers of any signatory State to develop, improve, utilize, control, or conserve the water resources of the upper Delaware River Basin within the boundaries of such State; provided, however, that the exercise of such powers by said State shall not conflict with the power of the Commission established by this compact with respect to those water resources authorized to be developed, improved, utilized, controlled, or conserved by such Commission."

It appears, therefore, that, with reference to the best interests of Pennsylvania, a substantial measure of the acceptability of the suggested legislation is the soundness and needfulness of the mandated project, or "a reasonable modification thereof." (See Section 2 of Article I of New York Act.)

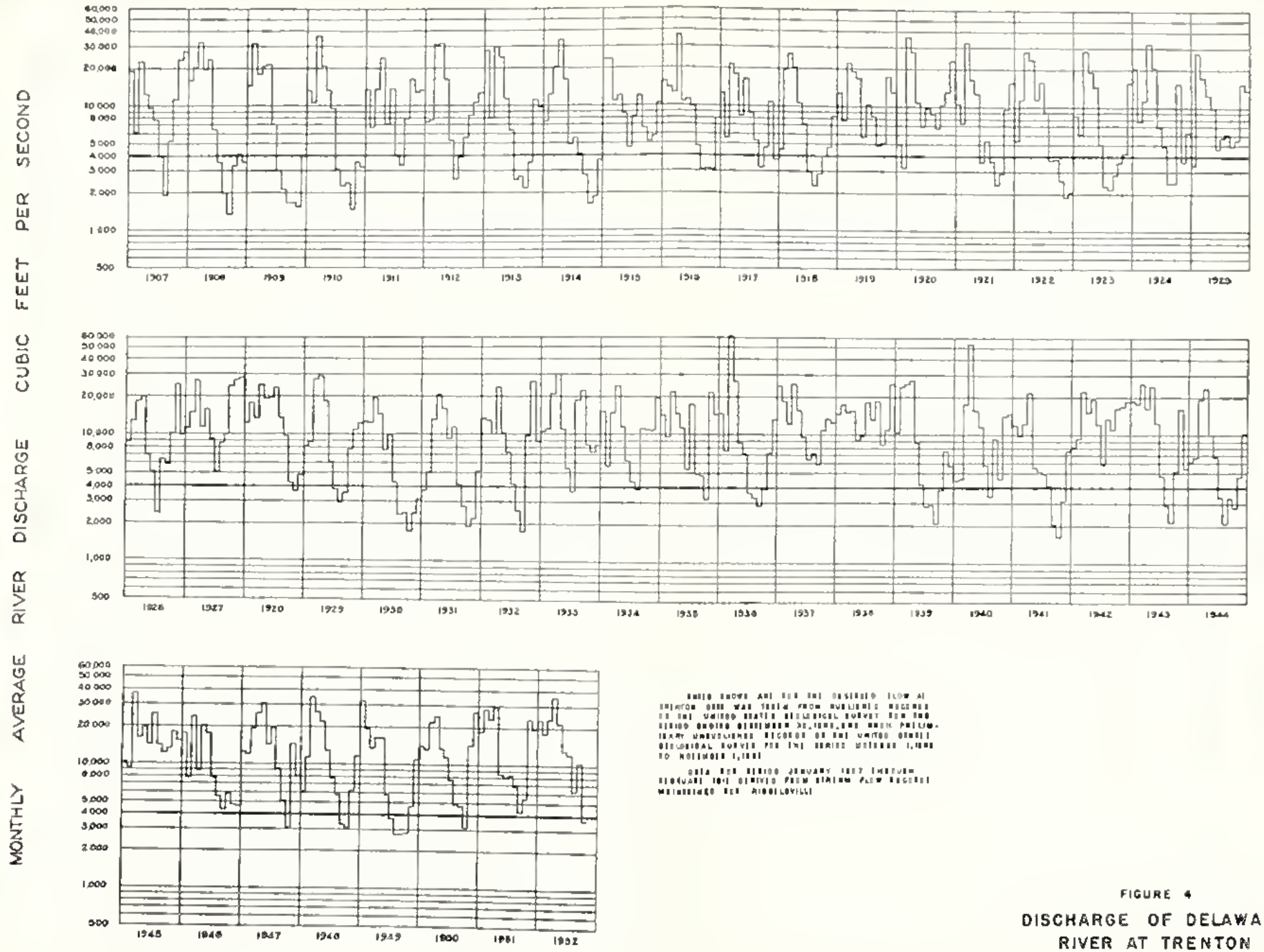
9. Comments on the Costs Proposed by Incodel

The estimated cost of Alternate A of Stage 1 of the Incodel project as of 1950 is as follows:

Construction Costs	$516,932,000
Interest during Construction	69,000,000
	$585,932,000

The estimated construction cost of Alternate A, Stage 1 is divided between that required for water supply and that required for stream flow regulation, but in this allocation the item for Interest during Construction is not included. The amount allocated to low flow augmentation is 19.6 per cent, or $101,429,000. No division of Construction Costs between the four states is given. However, allocations of the stream regulation part of the total annual cost are suggested as follows:

State or Commonwealth	Share of Each in Total Annual Cost Per Cent
New York	25
New Jersey	35
Pennsylvania	35
Delaware	5
	100



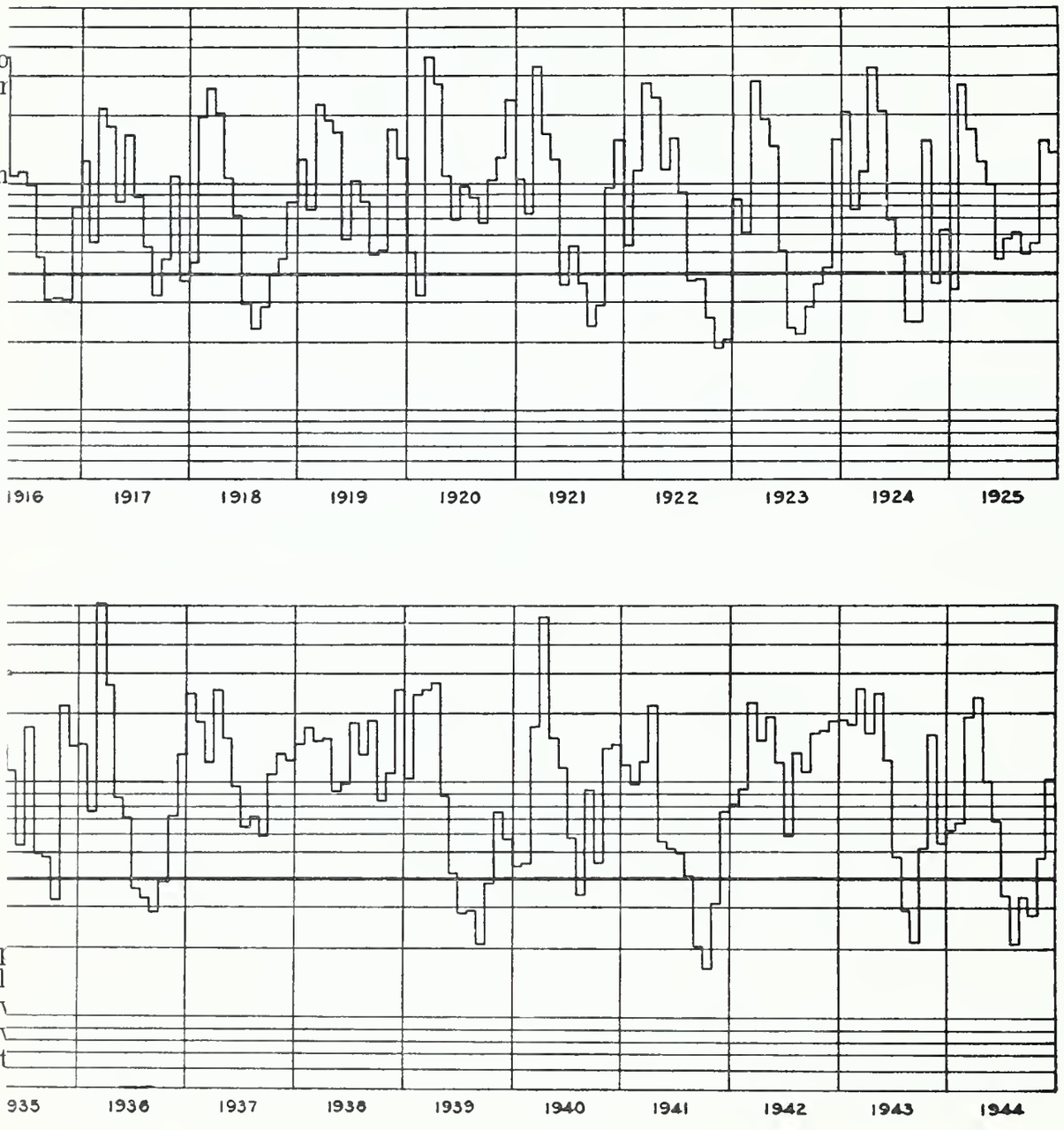
DATA SHOWN ARE FOR THE OBSERVED FLOW AT TRENTON 1908 WAS TAKEN FROM AVAILABLE RECORDS OF THE UNITED STATES GEOLOGICAL SURVEY FOR THE PERIOD BEGINS DECEMBER 26,1906, AND MORE PRELIMINARY OBSERVATIONS RECORDS OF THE UNITED STATES GEOLOGICAL SURVEY FOR THE SERIES BETWEEN 1,1906 TO NOVEMBER 1,1951

DATA FOR PERIOD JANUARY 1952 THROUGH DECEMBER 1952 DERIVED FROM STATION FLOW RECORDS MAINTAINED BY RIEGELSVILLE

FIGURE 4

DISCHARGE OF DELAWARE RIVER AT TRENTON

DECEMBER 1952



RATES SHOWN ARE FOR THE OBSERVED FLOW AT
TON. DATA WAS TAKEN FROM PUBLISHED RECORDS
THE UNITED STATES GEOLOGICAL SURVEY FOR THE
OD ENDING SEPTEMBER 30, 1949, AND FROM PRELIM-
Y UNPUBLISHED RECORDS OF THE UNITED STATES
LOGICAL SURVEY FOR THE PERIOD OCTOBER 1, 1949
NOVEMBER 1, 1952.

DATA FOR PERIOD JANUARY 1907 THROUGH
UARY 1913 DERIVED FROM STREAM FLOW RECORDS
TAINED FOR RIEGELSVILLE.

FIGURE 4

DISCHARGE OF DELAWARE RIVER AT TRENTON

DECEMBER 1952

TABLE 1

Allocation of Incodel Costs Between States

Stage 1, Alternate A

Item		Estimated Capital or Construction Cost		Estimated Total Annual Cost
Construction		$516,932,000	Total	$23,319,400
Interest during Construction		69,000,000	Net Revenue from Power	700,000
Total		$585,932,000		$22,619,400
Allocation				
Water Supply	80.4%	$471,000,000	80%	$18,095,500
Stream Control	19.6%	114,932,000	20%	4,523,900
Allocation of Stream Control Portion				
New York	25%	$ 28,800,000		$ 1,131,000
New Jersey	35%	40,200,000		1,583,350
Pennsylvania	35%	40,200,000		1,583,350
Delaware	5%	5,732,000		226,200
Total		$114,932,000		$ 4,523,900

On the basis of the foregoing information, and including interest during construction, the proportion of the estimated capital or construction cost for which Pennsylvania would be responsible is $40,200,000 for Stage 1, Alternate A, which covers only low flow augmentation. This computation and allocation is summarized in Table 1. When and if Pennsylvania wants a water supply from the Delaware River, substantial additional financing will be required of the Commonwealth, estimated now to be in excess of $140,000,000.

Since August, 1950, there has been a sharp increase in the Engineering News-Record Construction Cost Index, and it appears to be still rising. The increase has been over 15 per cent. On this basis, Pennsylvania's share in the construction cost would be increased to somewhat over $46,000,000. Perhaps over a construction period of 10 to 12 years, the capital amount allocated to Pennsylvania might be $50,000,000 or more.

Table 1 shows that the share of Pennsylvania in the estimated total annual cost of Stage 1 of the Incodel project is $1,583,350. At the present time, and under the assumptions in the Incodel Report, this annual share would amount to $1,800,000, and over the years might be $2,000,000 per year or more. In this connection, it should be noted that the debt service comprises the largest part of the total annual cost. It is computed as equal annual payments of 3.704 per cent over a period of 50 years, with an interest rate of 2.75 per cent. On the whole, this is a relatively low debt service. The estimated operating costs appear to be too low.

10. Delaware River Flow Quantities

As the quantities of water flowing in the Delaware River are of major importance, Figure 4 has been prepared to show the monthly flow or discharge at Trenton beginning with the year 1907, a period of 45 years and some months. Based on this record, the following information is pertinent:

Item	Water Quantity in C.F.S. or Number of Occurrences
River Flow at Trenton	
Minimum per 24 Hours	1,240
Month	1,632
Maximum Month	60,840
Annual Average	11,800
Number of Years in which the quantity was less than the following for more than one month in any year (of the 45 years, 540 months, of record)	
2,000 c.f.s.	9
3,000	23
3,400 (0.5 c.s.m.)	31
4,000	34
5,000	38
6,000	43
7,000	43
8,000	43

11. Areas

The Delaware River Basin has been well described in a number of other reports, beginning with House Document No. 179 by the U. S. Engineers. Data relating to areas are included in the following paragraphs.

The total drainage area of the Delaware River, not including Delaware Bay, is 12,757 square miles, located in four states, as shown on Figure 1, and is divided as follows:

State	Drainage Area Square Miles	Drainage Area Per Cent of Total
Pennsylvania	6,422	50.3
New Jersey	2,969	23.3
New York	2,363	18.5
Delaware	1,004	7.9
	12,757	100.0

The drainage area of the river above certain important points is summarized as follows:

Important Points	Drainage Area Above Designated Points in Square Miles
Port Jervis	3,076
Wallpack Bend	3,735
Trenton	6,780
Marcus Hook	10,400

The area of the Delaware River Drainage Basin in Pennsylvania, amounting to 6,422 square miles, has been divided by the Engineers' Study Commit-

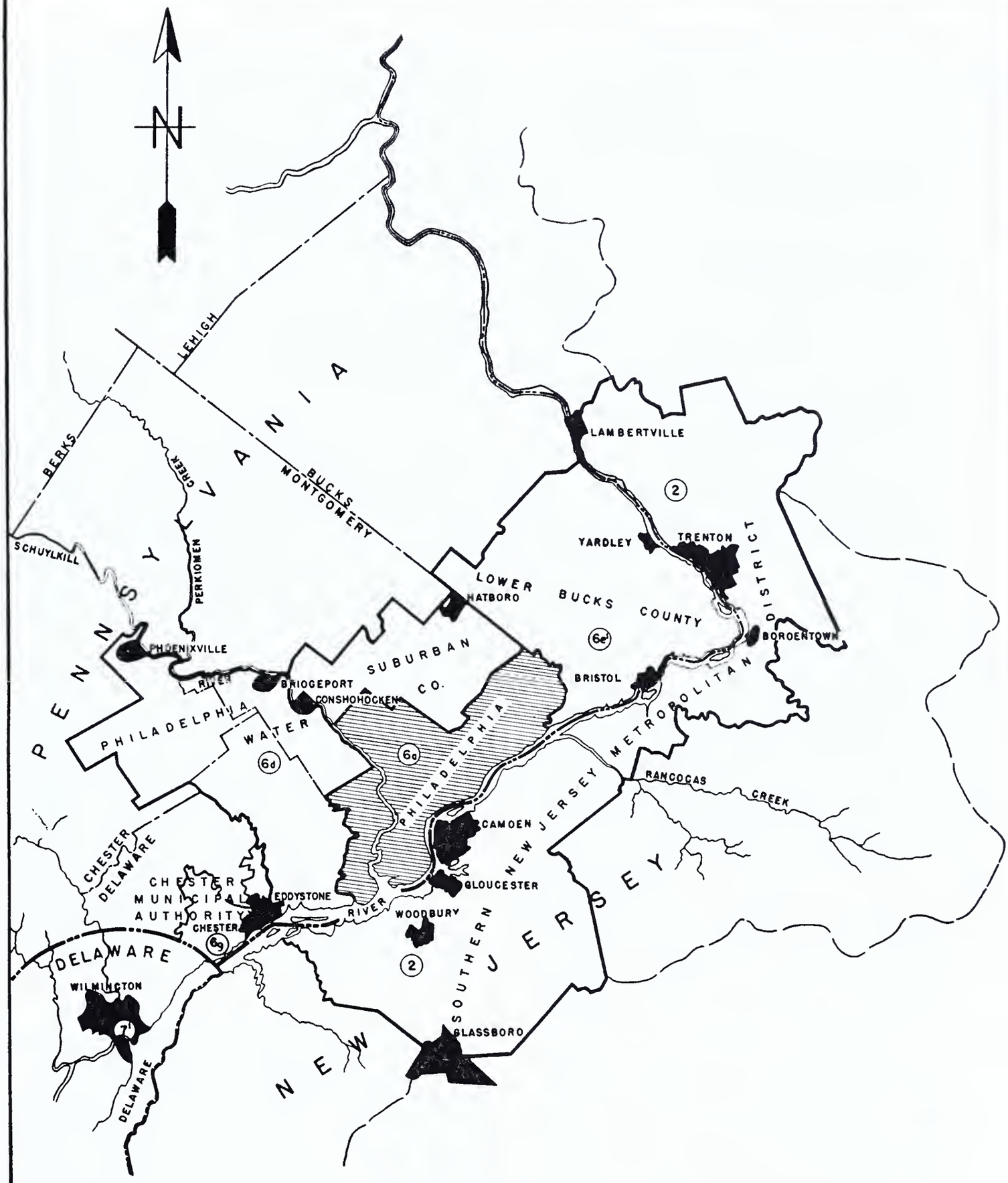


FIGURE 5

METROPOLITAN DISTRICT OF PHILADELPHIA AND SOUTHERN NEW JERSEY

DECEMBER 1952

SCALE OF MILES

0 5 10 15 20

tee, for study purposes, into six major parts, as follows:

Designation of Subdivision		Area of Subdivision in Square Miles
(a)	Philadelphia Metropolitan District (Including Lower Bucks County)	614
(b)	Drainage Basin of Schuylkill River above Philadelphia Metropolitan District	1,760
(c)	Lehigh River Basin	1,370
(d)	District above Easton which is largely rural	1,753
(e)	District below Easton — largely Upper Bucks County	403
(f)	District in Chester and Delaware Counties, excluding the Chester Municipal Authority and comprising mostly the Brandywine Creek Basin	522
		6,422

The Philadelphia Metropolitan District and the Metropolitan District of Southern New Jersey are shown on Figure 5. The so-called Chester-Marcus Hook area is also shown. As regards water supply for general purposes and for separate industrial use, these metropolitan districts are the most important parts of the Delaware River Drainage Basin and, therefore, have received particular attention. The areas of the principal parts of the metropolitan district are summarized as follows:

Incodel Designation	Description	Area in Square Miles	Acres
6a	Philadelphia	127.2	81,408
6d	Philadelphia Suburban Water Co.	274	175,360
6g	Chester Municipal Authority	28.	17,920
6e[1]	Lower Bucks County	185	118,400
	Total Pennsylvania Area	614.2	393,088
2	Southern New Jersey Metropolitan Area	514	328,960
7[1]	Wilmington*	9.8	6,272
	Total Area	1,138	728,320

* U. S. Census Land Areas

12. Populations

The Engineers' Study Committee has investigated the present and future populations in the Delaware River Drainage Basin in that portion of the basin which is in Pennsylvania and in the metropolitan district of Philadelphia. Estimates of these populations are stated in the Incodel Report of August, 1950, which were made prior to the U. S. Census of that year. To check the Incodel estimates, the populations resulting from the U. S. Census of 1950 have been tabulated and totaled, with the following results:

Item	1950 Population in Pennsylvania within the Delaware River Basin
Estimated in the Incodel Report	4,134,374
U. S. Census	4,061,420

Because of this close check, we have concluded to use, for the years 1950, 1960, 1980, and 2000, the populations in the Incodel Report, except as corrected for the recent industrial developments in lower Bucks County. This correction has increased the total estimated number of people for the year 2000 from 7,505,050 to 8,275,050, or an increase of 770,000. These estimated future populations within the Delaware River Basin are as follows:

	1950	1960	1980	2000
Pennsylvania	4,134,374	4,808,000	5,611,000	6,176,450
New York	85,500	85,600	85,500	85,400
New Jersey	951,200	1,222,900	1,479,100	1,727,200
Delaware	216,000	235,000	263,000	286,000
Total	5,387,074	6,351,500	7,438,600	8,275,050

Note: Populations for Pennsylvania and New Jersey increased over Incodel estimate for anticipated industrial expansion.

The populations in the metropolitan districts of Philadelphia and of southern New Jersey are most important as regards the use and development of th Delaware River for Pennsylvania. The boundaries of these districts are shown on Figure 5, and the populations are summarized in Table 2. The estimated future populations have been increased by the present and prospective large industrial expansion in Pennsylvania, mainly northerly of Philadelphia, and in New Jersey by the following numbers:

Year	Pennsylvania	New Jersey
1960	200,000	185,000
2000	400,000	370,000

TABLE 2

POPULATIONS

Metropolitan District of Philadelphia and of Southern New Jersey

Area or District		Population				
Incodel Designation	Description	Incodel 1950	U.S. Census 1950	1960	1980	2000
6a	Philadelphia	2,152,049	2,071,605	2,160,000	2,350,000	2,400,000
6d	Philadelphia Suburban Water Co.	501,000	480,932	645,000	935,000	1,224,000
6e[1]	Lower Bucks County	81,712	81,712	310,000	465,000	593,000
6g	Chester Municipal Authority	100,000	103,201	110,000	136,000	160,000
Total Population Pennsylvania		2,834,761	2,737,350	3,225,000	3,886,000	4,377,000
2	Southern New Jersey	575,000	662,388	805,000	978,000	1,095,000
7[1]	Wilmington	138,000	124,000	145,000	168,000	205,000
Total		3,547,761	3,523,738	4,175,000	5,032,000	5,677,000

The total estimated future populations in the Philadelphia metropolitan district, all in Pennsylvania, as estimated for the Incodel Report and by the Engineers' Study Committee, are as follows:

Item	Estimated Population for the Year 2000
Incodel	3,977,000
Engineers' Study Committee	4,377,000

All of the foregoing estimates of future population are considered to be conservative.

13. Water Needs of Philadelphia and the Lower Delaware Basin

At the present time a little over one-half of Philadelphia's water supply is taken from the Schuylkill River and the balance is taken from the Delaware River at Torresdale. In 1951, the total water pumpage was about 396 m.g.d. The present takings from the Schuylkill now about equal its safe yield without storage, so that any future increase in pumpage probably will have to come from the Delaware at Torresdale, or above. Easton and Bristol, Pennsylvania, and Phillipsburg, Trenton and Burlington, New Jersey, also obtain water from the Delaware River. Most of the other Pennsylvania and New Jersey communities depend upon well supplies which are only adequate to permit limited expansion. Chester, Pennsylvania, has recently discontinued the taking of water from the Delaware River and now obtains its water from Octoraro Creek. Present facilities are designed to filter 18 m.g.d., with provisions for expanding their output to 30 m.g.d., and later to a quantity approaching 75 m.g.d. The Philadelphia Suburban Water Company obtains its supply from tributaries of the Schuylkill and Delaware Rivers which are limited as regards future expansion. Present usage is about 31 m.g.d. It is understood that Wilmington, Delaware, has a satisfactory source other than the Delaware River. However, in the future, additional water from the Delaware might be required.

The qualities or characteristics of Philadelphia's water that have caused the most complaints in past years are corrosiveness, hardness, and tastes and odors. Generally speaking, the raw Schuylkill River water is less corrosive, but about three times as hard as that of the Delaware at Torresdale. No steps are taken to soften Schuylkill water, but in recent years Philadelphia's water treatment facilities have been greatly improved and thus the causes for, and the number of, complaints have diminished. In addition to those causes of complaint, there is a so-called "Aesthetic Complaint" that springs from the apparent foulness of the Delaware and Schuylkill Rivers at Philadelphia. It may somewhat lower the confidence of the public in the safety and potability of their water supply. It is the intangible quality or thing which permits rivals of Philadelphia and Pennsylvania to make adverse comments concerning Philadelphia's water supply.

There is no doubt that the water delivered to the Philadelphia distribution system is safe for domestic use. However, the quality of the Delaware River water at Torresdale has been deteriorating so that the difficulty and cost of providing adequate treatment has increased. The 1950 Annual Report of the Water Division of the Water Department of the City of Philadelphia states as follows:

> *"Oily or aromatic odors have been reported as predominant in the Delaware River water at Torresdale 74 per cent of the time. These are generally due to materials moving downstream from upriver sources and represent what is sometimes termed the 'Delaware River Taste.' The gassy, tarry, medicinal or musty odors were predominant 22 per cent of the time in the raw water, and at other times, after partial treatment in the plant, they become predominant. These types are due to pollution moving upstream from sources of pollution downriver from the plant. Conditions became such a filter effluents, on fifteen separate occasions in 1950, as to require the use of chlorine dioxide to destroy the tastes. A decided downward trend in the percentage of oxygen saturation at Torresdale is shown in Table No. 25 (f) for the past few years, also a decided increase in coliform organisms in the river water, Table 25 (a)."*

In the future, the quality of the river water at Torresdale will be affected by the following:

(a) Improved treatment of municipal sewage and industrial wastes as a result of the present Pennsylvania and New Jersey programs for pollution abatement.

(b) The unusually large industrial development in Pennsylvania between Morrisville and Philadelphia and that likely to follow in New Jersey between Trenton and Camden.

(c) The deepening of the channel above Philadelphia, the construction of new docks and the increased number of large vessels in anchorage above Torresdale.

Although the waste treatment program mentioned under (a) will be beneficial, the other developments will have to be very carefully controlled to avoid further deterioration of water quality at the Torresdale intake.

At the present time there is no definite official plan for a future water supply for Philadelphia. The matter has been given much consideration for many years. Beginning with 1865, over nineteen reports and plans have been presented. These many plans include, in general, the following

sources for a future water supply:

(a) A reservoir supplementing the Schuylkill River, such as one on Perkiomen Creek.

(b) Reservoirs on one or more creeks tributary directly to the Delaware River, such as the Tohickon, the Neshaminy, and others.

(c) Reservoirs on tributaries of the Delaware River, including the Lehigh and its tributaries, such as Tobyhanna and Bear Creeks.

(d) An intake on the Delaware River at such places as Yardley, Toch's Island, and Wallpack Bend.

Many combinations of these and other streams have been studied and advocated. All of the recent plans are based on a future water supply for Philadelphia of 500.0 m.g.d. The most recent study of record is the 1946 report of a Board of Engineers to the Mayor's Water Commission.

The following statement on this matter is taken from Page 45 of the Incodel Report of August, 1950:

"Philadelphia has been engaged in recent years in a program of extension and improvements of its existing facilities. It is believed that the City will probably continue to depend upon its existing sources for many years. Nevertheless, in 1947, Philadelphia filed an application with the Pennsylvania Water and Power Resources Board for a priority in rights, in respect to other Pennsylvania communities, for the future development of a new source of water supply by the construction of a dam in the main channel of the Delaware River at Wallpack Bend.

"Most certainly, any integrated project must make provision for a new source of water supply for Philadelphia to be constructed when and as deemed by that City to be necessary and advisable."

In the opinion of the Engineers' Study Committee, all projects for the development and use of the Delaware River or its tributaries must be designed so as not to preclude the taking of water to supplement or to supply not only the estimated future needs of Philadelphia, but also of the Philadelphia Suburban Water Company, of lower Bucks County and of southern New Jersey.

In considering the future water needs of those areas, the term "water quantities" is used to mean the quantity of water needed for people and for industry. It does not include water needed for the control of salinity or for augmenting low flows. Water quantities for people and for industry constitute the most important use of the Delaware River and its tributaries. The quantities of water estimated in the following paragraphs do not include large amounts taken directly from the river for cooling and condensing and returned to the river near the point of intake. Many things, related to the use and development of the river, affect water quantities, such as the following:

(a) Future populations

(b) Per capita water needs

(c) Future needs by industries

(d) Places on the river where the water is taken

(e) Places on the river where the used water is returned

(f) Re-use of river water.

Items (d) and (e) involve the matter of diversions and the question of whether those diversions are partial or complete, and whether or not they necessitate the release of stored water for compensation.

The present unit quantity of water pumpage in Philadelphia is about 165 gallons per capita per 24 hours (g.c.d.), but is considerably less in the suburban areas where there are few industries and where the water is mostly sold on a metered basis. However, a relatively high use of water is expected to occur in lower Bucks County. A future unit quantity of 165 g.c.d. for the future needs of Pennsylvania in the Delaware River Basin is not unreasonable. The estimated population of the Philadelphia Metropolitan District in Pennsylvania for the year 2000 is 4,377,000 (see Table 2, Section 12). Applying the estimated unit quantity to this population results in 720 m.g.d. as the estimated future water quantity that should be available for Pennsylvania. Probably an additional allowance should be made to provide for some usage outside of the Metropolitan District and for unknown future needs.

The distribution of the use of this water quantity is illustrated as follows:

Area or District in Pennsylvania	Estimated Future Water Quantity M.G.D.
City of Philadelphia	500
Philadelphia Suburban	100
Lower Bucks County	100
Chester-Marcus Hook	70
Above Morrisville	50
Allowance for unknown future needs	80
Total	900

It is recommended, therefore, that Pennsylvania

should have available for its use from the Delaware River a future quantity of 900 million gallons per 24 hours. The lower Delaware River Basin outside Pennsylvania may have a future need for an additional 250 m.g.d. This quantity of water is that needed for people and for industry, exclusive of water taken directly from the river for uses like cooling and condensing, or water required to be released as compensation for such diversions.

In 1946, a Board of Engineers recommended a reservoir on the Delaware River at Wallpack Bend as a source of water for Philadelphia. Water from the Lehigh River or its tributaries above Lehighton would be equally soft and pure, but might be slightly higher in color. Delaware River water from below the mouth of the Lehigh would be slightly harder, less pure, and aesthetically less desirable than the truly upland sources. However, these differences in raw water quality may be of little or no importance since water from any of those sources will probably be treated before distribution. A taking from the vicinity of Yardley would be considerably cheaper in first cost than would the transportation of water direct from upland reservoirs.

As indicated in Table 26 of their August, 1950, report, Incodel estimated the cost of a diversion dam at Yardley, together with the necessary tunnels, conduits and equalizing reservoirs for delivery of water to Philadelphia, to be $119,571,975, as compared with their estimate, Tables 27 to 29, of $320,330,797 for intake, tunnels, conduits and reservoirs for diversion directly from the Wallpack Bend Reservoir. Neither of these estimates include the cost of the Wallpack Bend dam and reservoir proper. If built within the next few years, these costs might amount to over $140,000,000 and $375,000,000 respectively.

We have been advised by members of the Water Department that under the new schedule of water rates the expected total annual revenue of the Water Division will be about $12,000,000. The problem of developing an upland source of water for Philadelphia was illustrated by assuming a cost of $119,000,000 for obtaining Delaware River water at Yardley. This, it was said, would add about $5,000,000 to the annual cost of the Water Division, mainly for debt service. Thus it appears that it would be necessary for Philadelphia to increase its present water rates by over 40 per cent to provide for a water supply from Yardley. To obtain water directly from the Wallpack Bend Reservoir (if it were built) would necessitate an increase in the present water rates of possibly 125 per cent if all of that cost were borne by Philadelphia and financed by water revenues.

As previously stated, the estimated water quantity needs of Philadelphia and the Lower Delaware River Basin from that river or its tributaries are estimated to be about 1,150 m.g.d., or approximately 1,800 c.f.s. Most of that water would be used in the Philadelphia-Camden area. As indicated in Section 10, this water need exceeds the minimum flow in the Delaware River at Trenton. Furthermore, the entire flow of the river could not be diverted around the huge industrial developments immediately below Trenton and Morrisville without causing serious impairment of the quality of water available to the industries for cooling and condensing purposes. Such excessive diversion would also be deleterious to other riparian users and to aquatic life between Philadelphia and the point of taking. Therefore, it is obvious that, regardless of whether the taking is at Yardley or at some point further upstream, one or more upland reservoirs will be required to store water during periods of high runoff for release during periods of low natural stream flow. In other words, some river regulation, or low flow augmentation, will be required. The Incodel project is one scheme for providing such regulation. However, as shown in succeeding sections, it can also be provided by less costly projects.

14. Wallpack Bend Reservoir and the Effect of Release Procedures

In the preceding section, mention was made of the fact that one or more upland reservoirs would be required for collecting flood waters and storing them for release during periods of low stream flow, regardless of whether the future water supply of Philadelphia and the Lower Delaware Basin was diverted at Yardley or at some point further upstream. The quantity of water to be released and the duration of the releases have an important effect on the yield of any reservoir for water supply.

Many different formulas have been proposed for governing the amount of such compensating releases in the case of partial diversions from the main channel of the Delaware River, but none of them has been incorporated in any existing laws. As previously noted in Section 5, a release procedure for the New York City reservoirs is stated in the 1931 decree of the Supreme Court, but this has not been tried out since those reservoirs have not yet been placed in operation. The Delaware River Water Supply Diversion Act, which was enacted by Pennsylvania in 1943, contains rules for governing releases from reservoirs on tributaries of the Delaware River, but this legislation has not become effective.

To illustrate the importance of releases, we have made a study to determine the safe water supply yield from the Wallpack Bend Reservoir alone, exclusive of the reservoirs proposed under the Incodel project, assuming various rates of release as proposed under different proposed formulas. For this study the Wallpack Bend project was taken as that outlined in the Incodel Report of August, 1950. The Flatbrook Reservoir was not included.

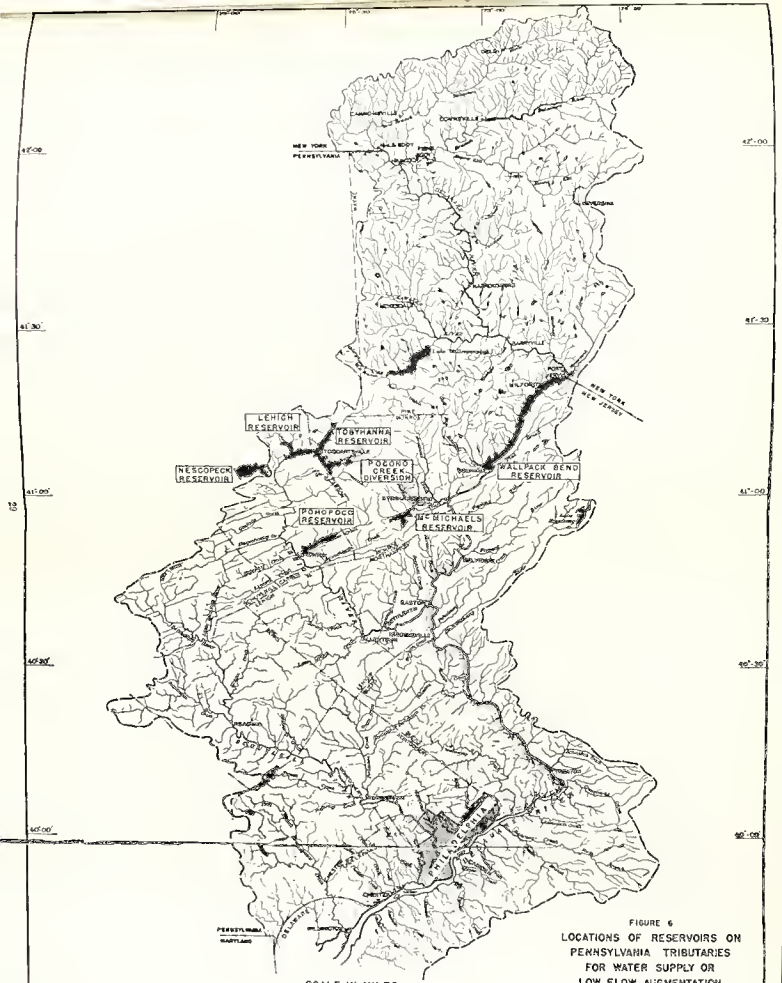


FIGURE 6

LOCATIONS OF RESERVOIRS ON PENNSYLVANIA TRIBUTARIES FOR WATER SUPPLY OR LOW FLOW AUGMENTATION

DECEMBER 1952

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As stated in Table 23 on page 135 of their August, 1950, Report, Incodel estimated the cost of this reservoir, exclusive of intake, conduits or other appurtenances for the delivery of water to Philadelphia and its vicinity, to be $47,222,735. If built in the next few years, this might amount to over $55,000,000. The general characteristics of the project are as follow:

Location of dam above mouth of Flatbrook Creek ..... 1 mile

Elevation of maximum water surface 420

Usable storage in billion gallons 91

Drainage area above dam in square miles 3,735

Hydraulic studies were made by mass diagrams using the records during the severe drought of 1930, 1931, and 1932. The water quantities were estimated for projects in which the water supply for the Philadelphia area and for southern New Jersey was diverted by conduit immediately below the dam as one project and from an intake structure near Yardley as another. It was assumed that the releases required from the two New York City reservoirs already authorized by the Supreme Court would be passed through the Wallpack Bend Reservoir. Nine cases related to various release formulae were studied as follows:

Case 1

This relates to a simple type of release procedure sometimes used by the Pennsylvania Water & Power Resources Board which, in general, requires a release of 0.15 cubic feet per second per square mile of tributary drainage area (c.s.m.).

Case 2

A release of 0.50 c.s.m., which is the control rate for determining the period during which releases should be made under the Decree of the Supreme Court in 1931.

Case 3

This case provides for a release of not less than 2,020 c.f.s. (1,306 m.g.d.), which is 30 per cent of the average annual rate of flow of the Delaware River at Wallpack Bend. The Supreme Court used this proviso in fixing the maximum rate of the releases from the proposed reservoirs in New York State.

Case 4

This is the rule stated in the Delaware River Water Supply Diversion Act of 1943. The act has never been made effective jointly by the abutting states. The release is related to a so-called control rate of 3,400 c.f.s. at Trenton.

Case 5

This comprises a modification of Case 4 to require a release at the rate of 0.24 c.s.m. when the natural flow is greater than 1,780 c.f.s. and a release equal to the natural at Wallpack Bend when it is below 1,780 c.f.s.

Case 6

This comprises the rule stated in the 1927 proposed "Compact as to the Waters of the Delaware River" which has never been ratified by all of the states. The rule is that 0.24 c.s.m. shall be maintained at the point of storage at all times when the natural flow above the point of storage is greater than that amount and a release equal to the natural flow when it is less than 0.24 c.s.m.

Case 7

This comprises the rule adopted by the Board of Consulting Engineers in its report dated April, 1946, entitled "A Future Water Supply for Philadelphia." It requires the release of all the natural stream flow whenever the flow is equal to or less than 0.60 c.s.m., and 0.20 c.s.m. whenever the natural stream flow at the point of development exceeds 0.60 c.s.m.

Case 8

This study was based on the assumption that the diversion at Wallpack Bend would be limited to 500 m.g.d. and that releases would be made from the Wallpack Bend reservoir as proposed under the 1927 Compact rule.

All of the foregoing cases were based on the diversion of water by conduit from the Wallpack Bend Reservoir. Case 9 was studied on the basis of diverting water at Yardley, rather than at Wallpack Bend.

Case 9

This study was based on utilizing the storage at Wallpack Bend to augment dry weather flows so as to make available the maximum dependable yield for diversion at Yardley. The 1927 Compact rule (see Case 6) was applied to fix the minimum flow to be maintained below the Wallpack Bend Dam. At Yardley it was assumed that only flows in excess of 0.24 c.s.m.

(1,630 c.f.s. or 1,050 m.g.d.) could be diverted from the river.

The results of our studies are summarized in the following table:

Case Number and Related Release Rule as Described Above	Resulting Minimum Flow at Trenton c.f.s.	Dependable Quantity Available for Water Supply m.g.d.
Diversion at Wallpack Bend		
1	1,178	1,014
2	2,486	168
3	2,638	70
4	967	711
5	1,757	583
6	1,514	796
7	1,714	464
8	2,545	500
Diversion at Yardley		
9	1,630	1,130

The foregoing indicates that the quantity of water available for diversion at Wallpack Bend during the driest period of record varies from 70 m.g.d. to 1,014 m.g.d., depending upon the rule of release and its application. At Yardley, 1,130 m.g.d. could be diverted to Philadelphia and communities adjoining the river below, at the same time maintaining a minimum flow at Trenton of 1,630 c.f.s. (1,053 m.g.d.) Therefore, release procedures are extremely important. The application of any particular release procedures to such a large Basin as that of the Delaware River is not predictable. Reasonable adjustments based on experience should be expected.

15. *An Alternate or Supplementary Source of Water for Pennsylvania*

In Section 13 it was estimated that the future water needs of the Lower Delaware Basin might be 1,150 m.g.d. Of that amount, 900 m.g.d. might be needed by Pennsylvania alone. In Section 14 it was shown that if a diversion was made at Wallpack Bend Reservoir, the dependable yield from that reservoir alone would not exceed 500 to 800 m.g.d., depending upon the release procedure followed. If the taking were made at Yardley, with controlled releases made at Wallpack Bend and below the intake at Yardley under the rule developed in the 1927 proposed Compact, it would be possible to divert 1,150 m.g.d. to Philadelphia and the Lower Delaware Basin, while maintaining a minimum flow at Trenton of 1,620 c.f.s. (1,047 m.g.d.) which is 7% lower than the minimum average monthly flow experienced in the 1930-31-32 drought. Should the diversion at Wallpack Bend be limited to 500 m.g.d. to Philadelphia, a minimum flow of 2,545 c.f.s. (1,644 m.g.d.) could be maintained at Trenton during the severest droughts. Thus it appears that if a truly upland source of water in the amount of 1,150 m.g.d. is desired for the Lower Basin and if minimum stream flows materially in excess of 1,600 c.f.s. at Trenton are deemed advisable, an additional or supplementary source of water would be needed. Such additional water could be made available by building reservoirs on tributary streams in Pennsylvania, which could supplement the Wallpack Bend project or vice versa. It would also be possible to secure this supplementary source by constructing the Flatbrook Reservoir in New Jersey and certain of the reservoirs in New York State as proposed by Incodel.

As an alternative to the Incodel plan we have investigated a number of reservoir projects on tributaries of the Delaware River, or adjacent thereto, all within the Commonwealth of Pennsylvania. Many such projects have been investigated in the past as sources of water for the City of Philadelphia and we have in addition investigated a further project, herein called the Lehigh-Nescopeck project, not previously considered by any agency. These projects were studied both from the point of view of water supply and also for low flow augmentation in order to determine the possibilities and costs of an intrastate project for comparison with the Incodel project. The most promising are the Lehigh-Nescopeck and Pohopoco projects, which might be combined, if found necessary, with the McMichaels-Pocono project. The location of these projects are shown on Figure 6.

The minimum flow which could be maintained at Trenton by these projects, if devoted solely to augmenting low flows, ranges from 3,865 to 4,880 c.f.s., depending upon the height of the dams and number of projects considered. If used primarily for the purpose of furnishing a gravity water supply to Philadelphia, the Lehigh-Nescopeck and Pohopoco combined project would yield a supply of 450 m.g.d. to the City, and if the McMichaels-Pocono project were added, a supply of 550 m.g.d. could be made available. Projects have also been considered in previous investigations by other agencies on Bushkill and Broadheads Creeks and on the Lackawaxen River and Shohola Creek.

The estimated construction costs for the most attractive projects for water supply or low flow augmentation are shown in Table 3. They range from $45,400,000 for the Lehigh-Nescopeck #2 project to $100,200,000 for the combined Lehigh-Nescopeck, McMichaels-Pocono and Pohopoco projects. These estimates of cost may be compared with the Pennsylvania share of the present day construction cost under the Incodel Plan of around

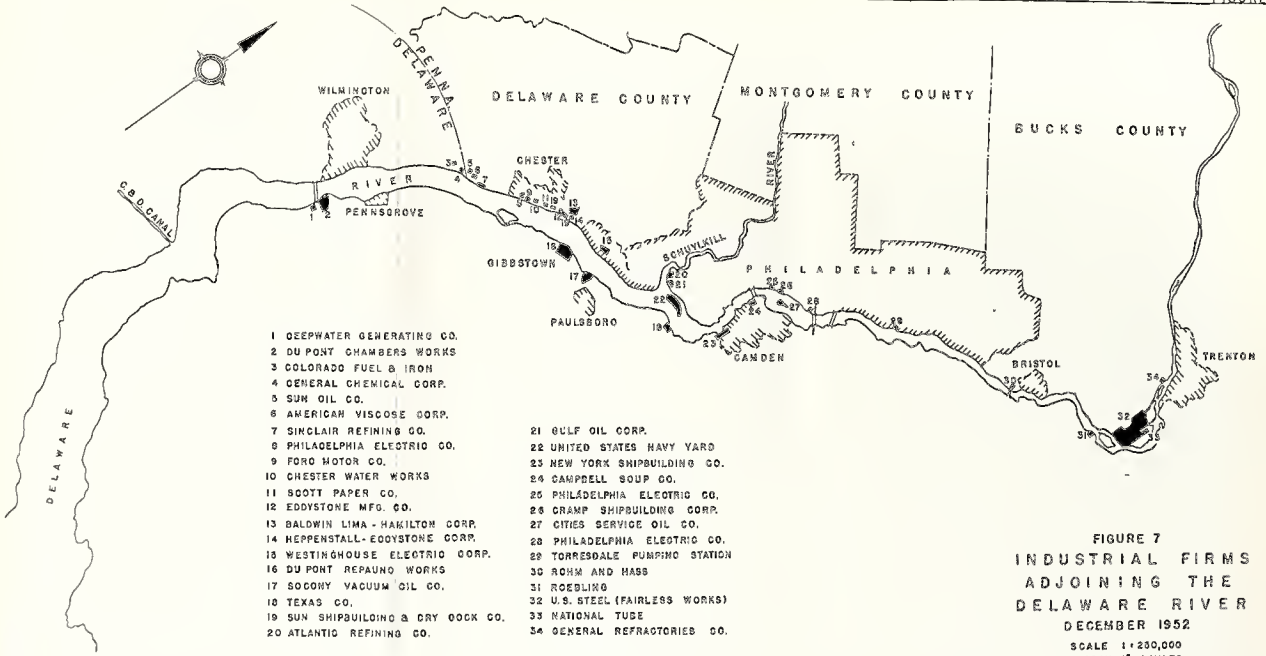


FIGURE 7
INDUSTRIAL FIRMS ADJOINING THE DELAWARE RIVER
DECEMBER 1952
SCALE 1:250,000
APPROX. 1" = 4 MILES

TABLE 3

SUMMARY OF PROJECTS

Project		Water Surface Elevation Full	Height of Dam in Ft.	Usable Storage in Billion Gals.	Minimum Flow at Trenton if Used for Low Flow Augmentation	Dependable Yield If Used For Water Supply M.G.D.	Estimated Cost of Project
Lehigh-Tobyhanna	No. 1	1,600	220	120.4	3,560	—	$29,500,000
	No. 2	1,583	203	84.5	3,360	231	23,900,000
	No. 3	1,560	180	54.6	3,075	192	16,600,000
McMichaels-Pocono	No. 1	620	170	99	3,115	—	34,500,000
	No. 2	590	140	58	2,885	99	23,000,000
Pohopoco	No. 1	650	195	45	2,765	79	16,300,000
	No. 2	622	167	27	2,630	65	12,500,000
Lehigh-Nescopeck	No. 1	1,320	250	150	4,060	—	49,400,000
	No. 2	1,300	230	105	3,865	367	45,400,000
Lehigh-Nescopeck and Pohopoco	No. 1	—	—	195	4,380	450+	65,700,000
Lehigh-Nescopeck Pohopoco and McMichaels-Pocono	No. 1	—	—	294	4,880	550+	100,200,000

Note: The foregoing estimates relative to the Lehigh-Nescopeck and Lehigh-Tobyhanna projects are in addition to capacity for flood control.

$46,000,000 for Stage 1, Alternate A (without Wallpack Bend Reservoir), or $77,000,000 for Stage 1, Alternate B (with Wallpack Bend Reservoir). It should be noted, however, that projects like the Lehigh-Nescopeck, Pohopoco and McMichaels-Pocono will also benefit New Jersey and the first of these projects could also be designed to provide adequate flood control for the Lehigh River Valley. Fair allocations of an estimated $49,400,000 to maintain a minimum flow at Trenton of 4,060 c.f.s. are illustrated as follows:

State	Illustrative Allocation of Estimated Cost of Lehigh-Nescopeck Project
New Jersey	$19,700,000
Pennsylvania	19,700,000
United States Government (for flood control)	10,000,000
Total	$49,400,000

The reservoir projects investigated include the following:

Designation	Elevation of Spillway
Lehigh-Nescopeck	1,320
	1,300
Lehigh-Tobyhanna	1,600
	1,583
	1,560
McMichaels-Pocono	620
	590
Pohopoco	650
	622

The Lehigh-Nescopeck project includes a large reservoir on Nescopeck Creek and a smaller diversion dam and reservoir on the Lehigh River. The valley of the Nescopeck would be used for storage and the drainage area of the Lehigh River for water. The principal parts of the project are as follows:

(a) An intake dam and reservoir on the Lehigh River

(b) A conduit from the Lehigh to the Nescopeck Reservoir

(c) A dam and reservoir on Nescopeck Creek

During periods of low flow the stored water in the two reservoirs would be discharged into Pine Creek and thence by way of the Lehigh River to the Delaware River. This project can be built with a relatively high dam with a water elevation in the reservoir when full of 1,320, or a lower dam with a water elevation of 1,300. The design can be prepared to reserve a volume in the reservoir equal to that proposed by the U. S. Engineers for flood control.

The characteristics of these reservoir projects are given in Table 3. Inspection of that table shows that even the combination of the Lehigh-Nescopeck, Pohopoco and McMichaels-Pocono projects could not be depended upon to yield a greater water supply than could be obtained from the Wallpack Bend Reservoir alone if the diversions were made directly at the reservoirs. The conveyance of water through closed conduits from these three reservoirs would probably be more costly than similar conveyance from Wallpack Bend alone. However, one or more of these reservoirs might be constructed to augment a water supply from Wallpack Bend if the entire Lower Delaware Basin were to be provided with an upland source of water. Although the McMichaels-Pocono project is closest to Wallpack Bend, the reservoir site might be costly to buy because of its present relatively high state of use and development.

The Lehigh-Nescopeck project, either with or without Pohopoco, is capable of supplying substantially as much low flow augmentation as proposed under the Incodel Plan at no greater, and probably considerably less, cost to the Commonwealth than that allotted to Pennsylvania under the Incodel Plan. It would have the added advantage of providing flood protection for the Lehigh Valley. The question of whether or not Pennsylvania needs, or would benefit, from the very appreciable low flow augmentation proposed by Incodel is dealt with in subsequent sections.

16. Industrial Water Supplies Directly from the River

Many industries located along the river below Morrisville take large quantities of water directly from the river. The major industries are shown on Figure 7. It is estimated that they take an annual average quantity of water from the river of over 3,200 m.g.d. Most of this water is used for cooling and condensing, and all of the spent water is returned to the river near the intakes. Computations show, however, that this large quantity of cooling water will not harmfully increase the temperature of the river water.

This stretch of the river may be considered in three parts. The first, or upper part, is from Morrisville to Philadelphia. Here, in Lower Bucks County, a very large industrial increase is expected, stimulated by the recent completion of the Fairless Steel Works.

The second, or middle part, comprises the Philadelphia water front along which are located many industries which take water directly from the river, the largest user being the Philadelphia Electric Company which is said to use almost 1,000 m.g.d. for cooling and condensing.

TABLE 4

INDUSTRIAL WATER USE

Industry	Softened	Quantity in MGD Filtered	Raw	Total
Lower Delaware County in Pennsylvania				
American Viscose Corp.	1.7	5.5		7.2
Scott Paper Co.	.2	12.0	1.65	12.85
Sinclair Refining Co.	2.0	.2	100.0	102.2
Sun Oil Co.	3.0	3.5	74.0	80.5
General Chemical Corp.	—	.73*	25.0	25.73
Philadelphia Elec. Co.	—	.06*	600.0	600.06
Ford Motor Co.	—	.29*	.40	.69
South Chester Tube Co.	—	.02*	1.0	1.02
Sun Shipbuilding Co.	—	.40*	3.0	3.4
Sub Total	6.9	22.7	805.05	834.65
Upper Delaware County in Pennsylvania				
Eddystone Mfg. Co.	.2	2.0		2.2
Baldwin-Lima-Hamilton Corp	.2		1.5	1.7
Heppenstall-Eddystone Co.	.2		20.0	20.2
Westinghouse Electric Corp.	.2		4.8	5.0
Total Pennsylvania	7.7	24.7	831.35	863.75
New Jersey				
Deepwater Generating Co.			300.0	300.0
DuPont-Chambers Works			73.0	73.0
DuPont-Repauno Works	.4		200.0	200.4
Socony-Vacuum Oil Co.	4.9	9.9	35.2	50.0
Totals	13.0	34.6	1,439.55	1,487.15

* This water purchased from the Chester Municipal Authority.

The third part is the so-called Chester-Marcus Hook area which is located between the mouth of the Schuylkill River and the Delaware-Pennsylvania state line. During periods of low upland runoff, ocean salinity penetrates into this stretch of the river. Industries located downstream from Eddystone are put to additional cost for water during such periods of high chlorinity. For much of the time the chlorides in this section of the river are well below 50 p.p.m. and often do not exceed 25 p.p.m. However, during invasions of ocean salinity, the chlorinity rises sharply and has reached a monthly average of 1,250 p.p.m. off Marcus Hook. Salinity invasions which add to the cost of industrial water supplies are estimated to occur forty-eight days a year on the average. The frequency, duration and severity of such invasions have increased in recent years.

The effect of high chlorinity on the cost of industrial water is characterized in the Incodel Report of August, 1950, as follows:

> *"Estimated average annual losses to some of the principal industrial plants in the Chester-Marcus Hook area caused by salinity incursion of the river for 1929 to 1944 inclusive, have been calculated by Incodel, based on data furnished by the industries. — From these figures, the estimated average annual losses to industrial plants in the Marcus Hook area caused by ocean borne salinity are estimated to amount to $762,000 per year."*

We have reviewed Incodel's original calculations as set forth in their "Survey and Report on the Effect of Salinity Upon the Delaware River as a Source of Industrial Water Supply Including an Analysis of Methods for the Control of the Problem," dated February, 1943, and find that their figures include not only the losses to industries, but also an allowance for softening the entire output of the Chester Municipal Authority and an allowance for the purchase of bottled water for drinking. Recently the Authority has discontinued taking water from the Delaware River, so such items are no longer valid components of the cost of salinity incursions. Industries which normally obtain their water from the Authority are no longer affected by salinity incursions and therefore industrial losses are reduced. To obtain an up-to-date estimate of the cost of high chlorinity, we investigated all of the major industries in the Chester-Marcus Hook area which use river water.

Table 4 shows the quantity of industrial water taken directly from the river and its treatment and use. Raw water for the industries in Pennsylvania amounting to 831 m.g.d. is used without treatment. The total amount of water requiring treatment in this area is 30.9 m.g.d., exclusive of water from the Chester Municipal Authority, or about 3.6 per cent of the total.

Our investigations indicated that the additional cost of water treatment and of maintenance of equipment to the Pennsylvania industries was approximately $200,000 per year. Most of this additional cost due to high chlorinity was incurred by the following industries:

American Viscose Corporation
Scott Paper Company
Sinclair Refining Company
Sun Oil Company

In addition to adding to the cost of water treatment and equipment maintenance, high chlorinity may cause some depreciation in the value of manufactured products. The estimation of such losses is difficult. The original Incodel estimates are understood to have included a figure for this loss. However, it appears that at the time of their survey, the principal losses of this type were incurred by the Aberfoyle Manufacturing Company, which concern is no longer operating in the area. The replies to our inquiries revealed that the relatively few industries in Pennsylvania which are now affected by chlorinity have no real product losses. They have developed adequate means of adjusting their water treatment and use, or have arranged to buy water for make-up and other limited uses from the Chester Municipal Authority or the Philadelphia Suburban Water Company.

Further, to illustrate the effect of high chlorinity on the industrial use of water and the related costs, we have investigated the practicability of acquiring water free of objectionable chlorinity. This can be accomplished in several ways, including the following:

(a) Purchasing from the Chester Municipal Authority.

(b) Pumping to storage when the chlorinity of the river water is low.

(c) Pumping from an up-river intake where the chlorinity of the river water is low.

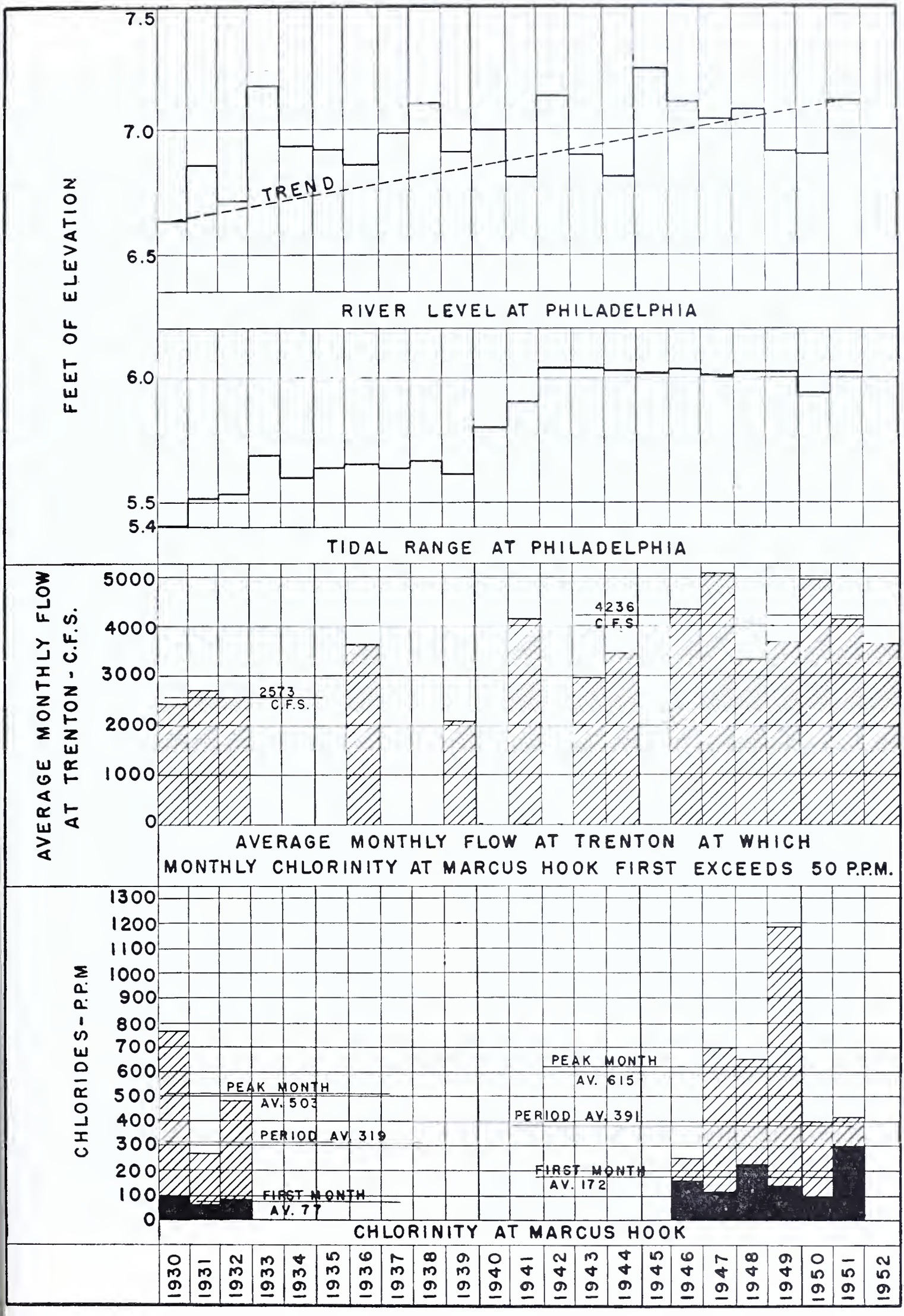
(d) Pumping to storage during low tide.

Water free of objectionable chlorinity can be supplied by one of the methods listed above or by a combination of them and in sufficient quantity to supply an estimated critical quantity of about 20.0 m.g.d. in the near future, for an estimated total annual cost of around $200,000, including operating costs and debt service.

17. Salinity Control

Ever since the white men discovered the Delaware Bay and River it has been known that saline ocean water penetrated many miles up the Estuary in sufficient amounts to impart a salty taste to its waters and make them unsuitable for many uses. As the shores became populated and indus-

FIGURE 8


FEET OF ELEVATION
7.5
7.0
6.5
TREND
RIVER LEVEL AT PHILADELPHIA
6.0
5.5
5.4
TIDAL RANGE AT PHILADELPHIA
AVERAGE MONTHLY FLOW AT TRENTON - C.F.S.
5000
4000
3000
2000
1000
0
4236 C.F.S.
2573 C.F.S.
AVERAGE MONTHLY FLOW AT TRENTON AT WHICH MONTHLY CHLORINITY AT MARCUS HOOK FIRST EXCEEDS 50 P.P.M.
CHLORIDES - P.P.M
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
PEAK MONTH AV. 503
PERIOD AV. 319
FIRST MONTH AV. 77
PEAK MONTH AV. 615
PERIOD AV. 391
FIRST MONTH AV. 172
CHLORINITY AT MARCUS HOOK
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952

tries requiring large volumes of water developed, it was observed that the limits of ocean salinity penetration were not fixed. The penetration was much greater during periods of low stream flow than it was at times of higher runoff. The importance of these periodic salinity invasions to Pennsylvania in general, and to the industries in the Chester-Marcus Hook area in particular, has been discussed under Section 16, which deals with "Industrial Water Supplies Directly from the River." This section deals with the causes and control of such invasions.

The total dissolved solids in ocean water are termed "sea salts." They consist of many compounds, but the most plentiful one is sodium chloride, or common table salt. The determination of "salinity," or concentration of "sea salts," in a brackish water requires a time consuming laboratory procedure. However, the determination of "chlorinity," i.e. the concentration of chloride ions, is a simple and rapid chemical test. Since the composition of sea salts is remarkably uniform the world over, the chlorinity determination is commonly used to measure the salinity of brackish water.

However, even the fresh upland water of the Delaware River is not entirely devoid of chlorides and additional chlorinity is imparted to it by the discharge of sewage and industrial wastes. Therefore, the presence of a few parts per million of chlorides does not necessarily indicate the presence of sea water. In the Chester-Marcus Hook area the normal spring-time chlorinity of the Delaware River is 20 p.p.m., or even less, so a chlorinity of 50 p.p.m. is a definite indication that sea water has penetrated up to that part of the River.

Only three salinity surveys of the upper Delaware River Estuary have been made that involved systematic collection and analysis of numerous samples up, down and across the river under various conditions. All were made between 1927 and 1935 and, by far, the bulk of the actual sampling was done in the years 1931, 1932 and 1933. Those surveys were as follows:

(a) Philadelphia District, Army Engineers 1927-35: No results were ever published, but all findings were made available to each of the following organizations.

(b) Delaware River Conservation Association, 1930-34: The Association believed that salinity movements in the Estuary were primarily dependent upon the fresh water inflow into it. The Association adopted 50 p.p.m. of chlorides during mean tidal conditions as an indication of sea water penetration and found that a flow of 7,200 c.f.s. at Marcus Hook was required to just hold the limit of such penetration below the Delaware-Pennsylvania boundary. On the assumption that the fresh water inflow varies in direct proportion to the tributary drainage area, such a flow is equivalent to 4,700 c.f.s. in the Delaware at Trenton, or 6,900 c.f.s. at Fort Mifflin and to 1,300 c.f.s. in the Schuylkill at Fairmont Dam Philadelphia, including diversions.

(c) Pennsylvania Sanitary Water Board 1931-35: The Board agreed with the Association that variations in fresh water inflow were the primary cause of salinity movements in the Estuary. It found that a flow of 5,100 c.f.s. at Fort Mifflin was necessary to prevent chlorinities in excess of 200 p.p.m. at high tide slack above the Pennsylvania-Delaware boundary. That flow was considered equivalent to a flow of 3,500 c.f.s. at Trenton.

Although no more recent surveys, such as those mentioned above, have been made, much data are available from routine sampling and analyses made by numerous water users up and down the river. The discussion of salinity movements in the Incodel Report of 1950 appears to be based largely upon the findings of the early surveys. The Engineers' Study Committee has attempted to avail itself of all data obtainable and have made a field search for it. Useful data of this nature was supplied to us by the following:

E. I. duPont de Nemours and Company records from their Chambers Works at Deepwater Point, New Jersey and their Repauno Works near Gibbstown, New Jersey.

Sinclair Refining Company records from their Marcus Hook Refinery.

Sun Oil Company records from their Marcus Hook Refinery.

Philadelphia Electric Company records from their Chester Station in Chester, Pennsylvania, and their Delaware and Southwark Stations in Philadelphia, Pennsylvania.

Chester Municipal Authority monthly records, including those of the old Chester Water Company.

Ford Motor Company additional data on daily variations in chlorinity of Chester municipal water.

Baldwin-Lima-Hamilton Corporation located between Chester and Eddystone, Pennsylvania.

Socony-Vacuum Oil Company records of their Paulsboro, New Jersey refinery.

Texas Company records of their Eagle Point Refinery near Westville, New Jersey.

Atlantic Refining Company data on chlorinity of the tidal portion of the Schuylkill River.

City of Philadelphia records of their Torresdale water filtration plant.

The following table was prepared from that data. It clearly shows that the frequency, duration and intensity of the salinity invasions have increased very considerably in recent years despite the fact that the river flow was generally higher during the recent invasions. The two bottom panels of Figure 8 further illustrate this change.

Changes in Chlorinity at Marcus Hook Shown by Averages for Eleven Year Periods

Period	*1930-40*	*1941--51*
Number of Years in Each Period	11	11
Number of Invasion Periods occurring in each eleven year period during which the average chlorinity exceeded 50 p.p.m. for one or more months	7	9
Total Number of Months when Average chlorinity exceeded 50 p.p.m.	22	36
Average Length of Invasion Period in months	3.5	4.0
Maximum Monthly Chlorinity	475	1,250
Average Chlorinity of the Invasion Periods	171	401
Peak Months of the Invasion Periods	287	690
First Months of the Invasion Periods	80	153
Average Flow of the Delaware River at Trenton in c.f.s. during Invasion Periods	4,887	4,939
Peak Months of the Invasion Periods	3,905	3,898
First Months of the Invasion Periods	3,920	4,009

The problem of sea water penetration into the Delaware Estuary is extremely complex and is influenced by a number of things. The more important factors which affect it include the following:

Ocean Salinity
Ocean Level
Sediment deposition
Dredging and channel changes
Construction of docks, piers and bridge abutments
River discharge
Tidal phenomena
Evaporation
Rainfall
Winds
Ship movements
Temperature

We do not believe that any reliable estimate of salinity movement can be based on river flow alone. Neither river flows nor tidal phenomena remain constant long enough to permit the establishment of an equilibrium condition, while numerous other factors influencing salinity movements are continually changing at slower rates. In our opinion, the limit of sea water penetration at any particular instant is the dynamic resultant of all these changing influences.

Since the salinity surveys made before 1935, there has been a marked increase in ocean level. This rise is believed by some authorities, to be due to a general warming of the world's climate and hence faster melting of the polar ice cap. The sharp increase in the rate of rise of the ocean level started in about 1930 and has continued at a fluctuating rate ever since. Along the Atlantic coast the rise has amounted to about 0.4 feet over the past twenty years. As a consequence, there has been a corresponding rise in the river level at Philadelphia, as shown by the top panel of Figure 8. Consultations with oceanographers, geologists, climatologists and other scientists indicate that it is impossible to forecast how long the ocean will continue to rise at its present rapid rate.

Other pronounced changes since those early surveys were made include the widening and deepening of the ship channel below Philadelphia, which occurred in 1940-41, and the pronounced increase in tidal range as illustrated by the second panel of Figure 8. We believe that together, these three major changes probably account for the pronounced increase in frequency, duration and intensity of the salinity invasions in the Chester-Marcus Hook area that has been experienced over the past 22 years. Possibly the rise in ocean level is the most important of the three factors.

As previously noted, the 1931-32 surveys indicated that a river flow of 6,900 c.f.s. at Fort Mifflin would suffice to prevent an average chlorinity in excess of 50 p.p.m. at Marcus Hook. Our study of more recent salinity invasions indicates that under present day conditions, a corresponding flow of about 9,500 c.f.s. would be needed. Should the ocean continue to rise, still greater flows would probably be needed in the future.

The Incodel Plan, or any similar scheme of low flow augmentation, would not affect the discharge of the Schuylkill River. A study of flows in the Schuylkill River, and of lesser tributaries below Trenton, indicates that, in order to maintain a 9,500 c.f.s. flow at Fort Mifflin, the Delaware River flow at Trenton would have to be above 6,300 c.f.s. for more than two-thirds of the June

to December period, and above 7,300 c.f.s. for at least one-third of that period.

The Incodel Plan would prevent the flow at Trenton falling below 4,000 c.f.s. (or below 4,800 c.f.s. with the Wallpack Bend reservoir). Although either of these flows is considerably greater than present minimums, they are not sufficient to prevent monthly average chlorinities of 200 p.p.m. or more at Marcus Hook, and 100 p.p.m. or more at Chester, under present conditions of ocean level, tidal range and channel dimensions. If the ocean level continues to rise, the Incodel Plan would be even less effective as a salinity control measure.

A detailed study of the Incodel Plan shows that although it would prevent extremely low flows at Trenton, it would actually increase the time that such flow was less than 6,000 and 8,000 c.f.s. by about 70 and 48 days, respectively, during an average year. Therefore, adoption of that plan would actually increase the frequency and duration of the salinity invasions. The increased duration of the invasions might average about 2 months a year.

Any temporary benefit from the Incodel Plan that might result from reduction in peak chlorinities during the invasions might well be overshadowed by the damage resulting from the greater frequency and duration of those invasions.

18. Sanitation

The term "Sanitation" refers to all matters relating to the use of the river for the final disposal of sewage and industrial wastes. Obviously, it is an important matter as regards the present water supply of Philadelphia and other communities taking water directly from the Delaware. It is probably the controlling factor in determining when, if ever, those communities will require an upland source of water. To an important though lesser extent, it affects the suitability of the lower Delaware River as a source of industrial water supply.

Numerous sanitary surveys of various portions of the Delaware River and its tributaries have been made from time to time by Federal, State and Municipal agencies, as well as by certain industries using river water. Based on studies of those data, as well as our own field investigations and on calculations of oxygen balances, we have concluded that a satisfactory sanitary condition of the river can be better obtained by the treatment of sewage and industrial wastes than by low flow augmentation. No practicable amount of low flow augmentation would justify any reductions in the degree of treatment now proposed for sewage and industrial wastes prior to their discharge to the Delaware River.

Augmentation of river flow affects sanitary conditions in two ways. First, it affords additional dilution at the point of entrance of sewage or wastes, thereby reducing the concentration of pollutants at that point, even though it does not reduce the actual pollution load on the river. Secondly, it results in higher river velocities and so decreases the time of travel between the point of entrance of such wastes and some downstream point of water usage. Time is essential if full advantage is to be taken of the self-purification capacity of the stream. Thus, although the dilution resulting from flow augmentation is beneficial, the resulting decrease in time available for natural purification is deleterious. The resultant effect on stream sanitation may be either helpful or harmful in any particular case. It will not be the same in all sections of the river.

The Delaware River, above Morrisville and Trenton, is relatively clean but, in comparison with the lower reaches, it is narrow and shallow with considerable fall. It is subject to relatively high velocities. Even when the discharge, at Trenton, is as low as 2,000 c.f.s., it is estimated that only three days are required for water to travel from Port Jervis, N. Y. to Trenton, N. J. At higher flows the time of travel becomes so short that only very limited self-purification can occur in the stream. Therefore, as shown in Table 5, bacterial pollution at the Trenton water intake is two to three times as great at flows of 4,000 to 5,000 c.f.s. as it is at flows of about 2,000 c.f.s.

Between Trenton and the mouth of Pennypack Creek the river is still comparatively narrow, but much deeper and flatter than above Trenton. Therefore, travel times are much greater. With a flow of 2,000 c.f.s. at Trenton, the average displacement time of travel from Trenton to the Torresdale intake is about 16 days. Doubling the flow would practically cut the time in half since the depth of water in this zone is more a function of tides than of fresh water inflow. Despite these longer retention times, increases in fresh water inflow at Trenton up to some 6,000 to 7,000 c.f.s. still result in increased bacterial pollution at Torresdale. The beneficial effect of dilution is not sufficient to overcome the harmful effects of time reduction, until the flow at Trenton exceeds 10,000 c.f.s., as shown in Table 5. As indicated by the following table, our calculation of oxygen balances in this zone for about the year 2000, and assuming the presently proposed degree of sewage and waste treatment, indicate that, during the warm summer months, much the same effect will be discernible in the oxygen balance at both the Bristol and the Torresdale water intakes.

TABLE 5

Variation of Coliform Bacteria with
Stream Flow in Various Zones of Delaware River

Range in Flow of Delaware at Trenton Cu. Ft. per Second	Most Probable Number of Coliform Bacteria per Milliliter of Water		
	Zone I	Zone II	Zone III
	Trenton Filtration Plant Intake Daily Average June to Sept. Inc. 1946-1951 Inc.	Torresdale Intake Philadelphia Monthly Averages 1926-1951 Inc.	Chester Waterworks Intake Monthly Averages 1931-1940 Inc.
Less than 2000	19	200	2,235
Between 2,000 and 3,000	40	250	3,340
3,000 and 4,000	33	240	2,733
4,000 and 5,000	67	250	4,264
5,000 and 6,000	68	230	2,798
6,000 and 7,000	66	310	1,979
7,000 and 8,000	66	230	3,419
8,000 and 9,000	93	250	1,717
9,000 and 10,000	65	240	2,991
10,000 and 15,000	84)	180	2,697
15,000 and 20,000	148)		2,549
20,000 and 30,000	178	170) 180)	2,610
30,000 and 40,000			
Over 40,000		110)	

Calculated 5 Day Biochemical Oxygen Demand and Dissolved Oxygen Concentrations in Parts Per Million at Bristol and Torresdale in about the Year 2000 With Treatment of Sewage and Wastes to the Degree Now Proposed and a River Temperature of 77°F

Mean Flow at Trenton c.f.s.	Bristol		Torresdale	
	B.O.D.	D.O.	B.O.D.	D.O.
2,000	1.4	6.6	0.2	8.0
3,000	2.2	5.8	0.7	7.3
4,000	2.7	5.6	1.1	6.7
5,000	3.0	5.5	1.6	6.3
6,000	3.2	5.5	1.6	6.3
8,000	3.6	5.7	2.4	5.7
10,000	3.8	6.1	2.8	5.6

Between Pennypack Creek and Marcus Hook the estuary is so broad and deep that under all but the highest flows the retention period in this zone is sufficient to utilize most of its self-purification capacity. At a total discharge of 5,000 c.f.s. in the Delaware and Schuylkill Rivers, the displacement time is about 34 days. The principal source of oxygen in this zone is that absorbed from the atmosphere over its broad surface. The dissolved oxygen contributed by the river inflow from above, is very small in comparison with that obtained by surface reaeration. Because of these two facts, variations in fresh water inflow to this zone have relatively little effect upon its capacity to assimilate pollution.

The results of surveys of this section of the river, made by the City of Philadelphia during the summers of 1949, 1950, and 1951, are shown on Figure 9. (Some of the peaks in these curves are probably due to the fact that the new Philadelphia Northeast Sewage Treatment Plant started operation during 1951. The new plant provides a higher degree of treatment than did the old.) These curves show that under present conditions no recovery, or increase in dissolved oxygen, occurs until the river flow exceeds 7,700 c.f.s. and that a dissolved oxygen saturation of 40 per cent is not accomplished by a river flow of 9,500 c.f.s.

An appreciable portion of the present burden on the self-purification capacity of this lower zone is due to the oxygen demand of the sludge deposits that have accumulated in that zone over the past years when most sewage and wastes received little or no treatment. The presently proposed degree of treatment for sewage and wastes tributary to this zone will materially reduce, but not wholly eliminate those sludge deposits. Therefore, they will continue to exert a pronounced, though diminished, demand on its oxygen resources.

Although a four state reciprocal agreement established a minimum degree of treatment for wastes tributary to this zone, such as would affect a 35% reduction in their oxygen demand, New Jersey is requiring sufficient treatment to give a 70% reduction. Philadelphia has provided sufficient treatment to yield a 75% reduction at its Northeast Sewage Treatment Plant, but for 35% reduction at its Southeast and Southwest plants. If Philadelphia were to expand those plants to provide 75% reduction, then the remaining deposition of sludge in the zone would be so slight that it would have a negligible effect on the oxygen balance in that zone.

It is estimated that the initial construction cost of providing such expanded treatment at the Southeast and Southwest Philadelphia plants would be about $18,500,000. Increased annual operating costs for such expanded treatment, exclusive of fixed charges, are estimated at $380,000 when those plants are operating at design capacity. It might be somewhat less under present loadings.

Although the evidence of the various sanitary surveys tend to refute the Incodel statement that augmentation of low river flow would improve sanitary conditions, the Engineers' Study Committee felt that, in view of the major changes in pollution load that will result from the present waste treatment programs of Pennsylvania and New Jersey, it would be desirable to calculate oxygen balances for the critical section of the river between Trenton and Marcus Hook. Similar calculations for the river above Trenton were not warranted because of its good oxygen balance under present conditions.

The population equivalents of the sewage and industrial wastes tributary to the critical section of the river were estimated to be as follows:

	1949-50 Conditions		Conditions in About the Year 2000	
	Before Treatment	As Discharged	Before Treatment	After Treatment to the Degree now Proposed
Sanitary Sewage	2,812,000		4,522,000*	
Industrial Wastes	2,420,400		3,982,000	
Total	5,232,400	4,632,200	8,504,000	3,043,600

* The estimated population of the Pennsylvania and New Jersey portions of the Metropolitan District of Philadelphia and Southern New Jersey for the Year 2000 is

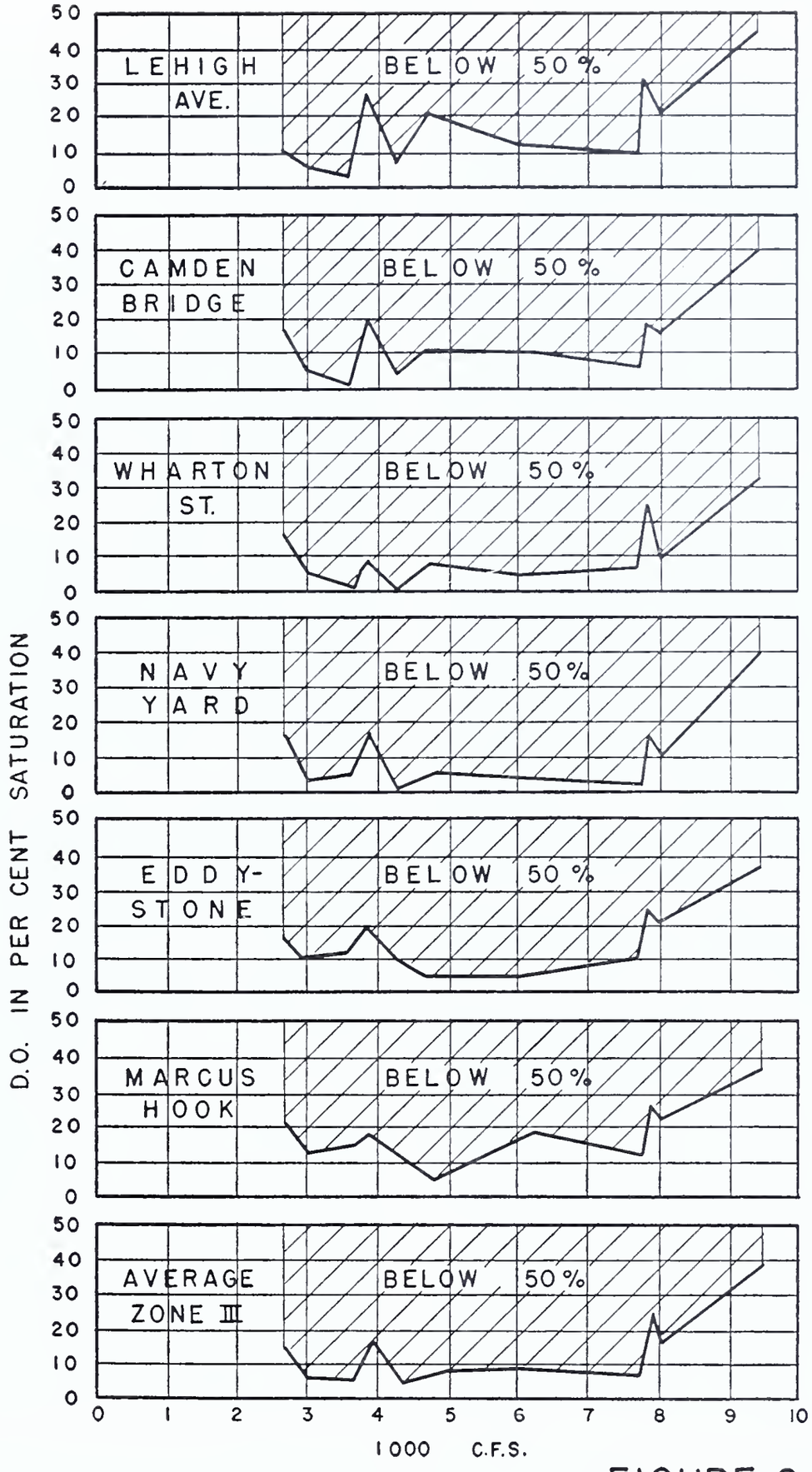


FIGURE 9

NOTE: THESE RIVER SURVEYS SHOW NO RECOVERY OF D.O. UNTIL THE RIVER FLOW EXCEEDS ABOUT 7700 C.F.S. AND HAS NOT REACHED 50% D.O. SAT. WITH A RIVER FLOW OF 9500 C.F.S.

RELATION OF D.O. AND DELAWARE RIVER FLOW AT TRENTON BASED ON 13 ACTUAL RIVER SURVEYS MADE BY THE CITY OF PHILADELPHIA. MADE BETWEEN AUG. 1949 AND SEPT. 1951

DECEMBER 1952

5,472,000. However, that District includes communities whose treated wastes will be discharged to non-tidal portions of Delaware River tributaries. It is assumed that the oxygen resources of these tributaries will be adequate to stabilize the pollution resulting from such discharges without placing an appreciable load on the tidal portion of the Delaware River.

Oxygen balance calculations require a mass of complex and highly technical data, not all of which was obtainable from the previously mentioned surveys. Some assumptions, based on experience and judgment, have been required. The calculations are necessarily approximate.

Our calculations indicated the following:

a. The presently proposed degree of treatment may be adequate to maintain a minimum of 50% oxygen saturation in the estuary between Pennypack Creek and Marcus Hook during the first years after it goes into effect but, by about 1975 that degree of treatment will only be adequate to maintain an oxygen concentration of 2 to 3 parts per million. Although a minimum oxygen concentration of 2 to 3 p.p.m. should be enough to prevent nuisance conditions, it is not enough to comply with the minimum of 50% saturation prescribed by the aforementioned four state reciprocal agreement. It falls considerably short of the 5 p.p.m. minimum said to be necessary to avoid interference with normal shad runs.

b. If it is desired to comply with the four state reciprocal agreement in about the year 1975 and maintain a minimum oxygen saturation of 50%, it will be necessary to either expand the degree of treatment now proposed for the sewage and wastes from the southeast and southwest districts of Philadelphia to yield 75% instead of 35% oxygen demand reduction, or maintain flows of at least 8,500 c.f.s. at Trenton during warm weather. It is probable that no low flow augmentation would be required when river temperatures were 50° F. or lower.

c. Even with expanded treatment of Philadelphia's sewage, it may not be possible, in the year 2000, to maintain 50% oxygen saturation during extreme warm weather at Trenton flows of less than about 8,000 c.f.s. However, the treatment of all sewage and wastes could be further improved at that time if conditions warranted.

d. Even with expanded treatment of Philadelphia's sewage, the 5 p.p.m. of dissolved oxygen, said to be the minimum for shad fishery, can probably not be maintained at Trenton flows of less than about 8,500 c.f.s. By the year 2000 a flow or more than 9,000 c.f.s. might be required unless a still higher degree of treatment was provided for all sewage and industrial wastes.

The results of our calculations agree with our findings from the available sanitary surveys and indicate that the maintenance of minimum flows of 4,000 to 4,800 c.f.s. at Trenton, as proposed by Incodel, will not have any appreciable beneficial effect on sanitary conditions in the lower portion of the river between Pennypack Creek and Marcus Hook. Such flow regulation might actually increase rather than decrease the harmful effect of pollution at the existing Trenton, Bristol, Burlington and Torresdale water intakes. Certainly it could have no real benefit. Therefore, it does not appear that any expenditure for the Incodel project can be justified on the basis of expected improvements in sanitary conditions on the Delaware River, or in the reduction of the cost of sewage and industrial waste treatment.

19. Navigation and Port Facilities

The so-called Philadelphia Harbor comprises the Delaware River and its estuary downstream of the Trenton Dam and the Schuylkill River downstream of the Fairmont Dam, together with several minor tributaries and connected canals. The port facilities are excellent and are being improved from time to time by deepening and widening the ship channels. A project is now under consideration for extending a deeper and wider channel to Morrisville, which, if completed, will facilitate shipping for the Fairless Steel Works and other industries above Philadelphia on both sides of the river. The importance of the harbor is indicated by the following comparative traffic activities:

Comparative Statement of Water-borne Traffic in Short Tons

Year	Port of Boston, Mass.	Consolidated Port of New York	Delaware River and Tributaries, Trenton, N. J. to the Sea	Baltimore Harbor and Channels Maryland
1950	19,446,897	144,943,558	69,080,525	35,640,406
1940	19,018,305	129,712,186	42,087,213	26,905,898
1930	15,689,632	120,395,645	31,315,145	17,114,218
1920	6,290,389	117,865,396*	26,611,128	16,465,975

* for 1924

Information obtained from Annual Report of the Chief of Engineers, U. S. Army, Part 2.

The foregoing traffic quantities indicate that up to 1950 the lower Delaware River increased its water-borne traffic at a considerably higher rate than the others. The increased traffic to serve the Fairless Steel Works and the industries likely to be attracted to the lower river areas in the future, will probably accelerate this higher rate of increase.

It is, of course, important that the present and future use of the port facilities be maintained.

The following things could have an effect on navigation and on the port facilities, if they became sufficiently adverse:

a. Floods

b. Silt

c. Pollution

As stated elsewhere in this report, none of the foregoing things are expected to become adverse even without river regulation and low flow augmentation, provided the degree of sewage treatment proposed by the Departments of Health of New Jersey and of Pennsylvania is completed and that channel depths are maintained by dredging to offset the shallowing effect of silt. The experience up to the present time has not indicated any difficulty on account of floods.

Should there be important developments of inland waterways in the future, as between the Delaware and the Raritan rivers, the need for low flow augmentation should be restudied.

20. Flood Control

Unlike many of the larger river basins in the United States, the Delaware River Basin is not confronted with a serious flood problem. The valley of the Delaware River itself has suffered very little from floods in the past, and it is estimated that the annual preventable damages due to floods amount to only $90,000. There are no flood control projects on the Delaware River inasmuch as no proposed project has been found economically justifiable.

The preventable annual flood damage in the Lehigh River Valley is estimated at $722,000. The Corps of Engineers, U. S. Army, determined that the annual benefits would exceed the annual costs of a reservoir flood control project located on the Lehigh River just downstream from the mouth of Bear Creek. The intake reservoir proposed by the Engineers' Study Committee for the Lehigh-Nescopeck Projects is identical with the reservoir proposed by the Corps of Engineers and its operation will be such that it will at least equal the flood control effectiveness of the Corps of Engineers project.

The Engineers' Study Committee investigated the feasibility of including flood control storage as part of the Lehigh-Tobyhanna Projects. It was found that the flood control effectiveness of a reservoir located on the Lehigh River below the mouth of Tobyhanna Creek would not be as great as that of a reservoir located below the mouth of Bear Creek but that the additional construction cost incurred by including flood control storage in Tobyhanna Reservoir would be only half the cost of constructing the project below Bear Creek.

The Lackawaxen River Valley suffered great damage during the May, 1942 flood when 24 lives were lost and the property damages exceeded 6 million dollars. The relatively infrequent occurrence of floods, however, reduces the annual preventable damages to $98,800. The Corps of Engineers, U. S. Army, found that it was not economically feasible to construct a flood control project on the Lackawaxen River but nonetheless recommended the construction of one earth dam on the Lackawaxen River upstream from Honesdale and a second on Dyberry Creek, a tributary which enters the Lackawaxen River at Honesdale, on the basis that these reservoirs would safeguard lives and afford social security to the inhabitants. No action has been taken on this proposal, but the town of Honesdale has, at its own expense, improved the carrying capacity of the channel of the Lackawaxen River through the town by removing three low dams which formerly obstructed flow. Furthermore, the Pennsylvania Department of Forests and Waters has constructed several hundred feet of concrete wall along the Lackawaxen River for the purpose of protecting certain areas from flooding and is currently removing flood debris from the channel in Honesdale. The Department is also considering a project to improve the channel of the Lackawaxen River through Honesdale and the channel of Dyberry Creek for a short distance above its mouth.

The maximum floods of record on the Delaware River are summarized as follows:

Date	Magnitude at Trenton in c.f.s.
Jan. 8-11, 1841	208,000
June 5-8, 1862	215,000
Oct. 4-5, 1869	178,000
Dec. 16, 1901	199,000
Feb. 28 - Mar. 2, 1902	226,000
Oct. 10-11, 1903	284,000
Feb. 10-14, 1925	154,000

As regards the design of the Lehigh-Nescopeck project for flood control, this is a desirable project, in our opinion.

21. Silt Control

In connection with any dam and reservoir project it is advisable to give some consideration to the sediment load that will be washed into the reservoir from the drainage area above, since the deposition of that sediment might eventually accumulate to such an extent as to reduce the usable reservoir capacity. Although such deposition is normally objectionable, it might, in the case of the Delaware River and its tributaries, be of some benefit

in reducing water treatment costs or the amount of dredging required to maintain authorized channel dimensions in the tidal estuary.

The U. S. Geological Survey has measured the suspended sediment discharge of the Delaware River at Morrisville since September, 1949, the Lehigh River at Walnutport since June, 1948, and the Schuylkill River at Philadelphia since November, 1947, as well as at several other points along the Schuylkill above Philadelphia. From these data, the suspended sediment burdens of the three rivers average as follows:

Point on River in Pennsylvania	Tons per Month, Dry Basis Total	Per Square Mile of Drainage Area
Lehigh at Walnutport	23,800	18.6
Delaware at Morrisville	77,600	11.4
Schuylkill at Philadelphia	122,000	64.3

Much of the sediment carried by the Schuylkill is due to coal mining operations. In 1947 the Commonwealth, with the cooperation of the Federal Government, initiated the Schuylkill River Restoration Project which, upon completion, will materially reduce the sediment burden of that river.

A survey report of soil erosion and allied problems in the Delaware Watershed made by the U. S. Department of Agriculture in 1949-50 indicated that the average annual damage due to sediment deposition within the Basin was $898,100 of which $747,500 represented the cost of dredging an estimated 2,300,000 cubic yards of eroded sediment from navigable channels and docks in the Delaware estuary. We are advised by the Philadelphia District Office, Corps of Engineers, U. S. Army that it is necessary to dredge about 15,000,000 cubic yards a year to maintain the full 40 foot depth of channel below Philadelphia. Additional dredging is required at docks and piers. The Corps of Engineers attribute most of this shoaling to movement of the estuary bottom due to imperfect hydraulic design and not to the inflow of upland silt.

Concerning loss of reservoir capacity due to sedimentation, the above mentioned survey by the Department of Agriculture found that the annual loss of storage capacity in reservoirs having an initial volume of more than 150 acre-feet per square mile of drainage area, was usually so low as to be economically unimportant. All of the reservoirs considered by the Engineers' Study Committee are in that category.

We conclude that the matter of silt control is relatively unimportant so far as the Incodel project, or any alternative project, is concerned. Silt deposition would not seriously deplete the capacity of such reservoirs.

22. Power

The Incodel Report of August, 1950 devotes several pages to a discussion of power development in connection with the proposed integrated water project. The statement is made that

> *"The primary purpose of the proposed integrated water project is for water supply and stream flow regulation. Power development, considered to be of secondary importance, is included only where it can advantageously utilize water released for other purposes."*

With this statement we agree. The detailed studies of available power described in the Incodel Report reach the conclusion that the net revenue from power development in the Incodel Plan may amount to $700,000 per year. This net revenue is about 3.0 per cent of the estimated total annual cost. Power development, therefore, does not materially affect the advantages and disadvantages of the integrated project.

There is a market for power in and near the Delaware River Basin. The amount of hydro-electric power that may be generated in connection with the dams and reservoirs comprised in the Incodel Plan, however, is very small compared to the demand. Hydro-electric power is essentially a secondary matter in the Delaware River Basin.

In our opinion, care should be taken that no power dams are built in the Delaware River Basin which would adversely affect other uses of the river, of which water supply is the most important.

23. Recreation and Fishing and Hunting for Sport

Among the needs for stream flow regulation in the Incodel Report is recreation. The relation of reservoirs to recreation and to fishing and hunting for sport has been brought to the attention of the Water Resources Committee by the Pennsylvania chapter of the Isaac Walton League. For these reasons, the Engineers' Study Committee have investigated this matter and, with the approval of the Water Resources Committee and of the Commonwealth, have arranged with the U. S. Fish and Wildlife Service and with Dr. Ira N. Gabrielson, President of the Wildlife Management Institute, to make field investigations and reports on the effect of the proposed reservoirs on fishing and hunting.

Our own study has been directed to other recreational matters. The reports by Dr. Gabrielson and by the U.S. Fish and Wildlife Service are filed with the Commonwealth. It should be noted that the construction of reservoirs may or

will effect the submerged land and its immediate environs in the following major ways:

a. The elimination of land suitable for hunting.

b. The elimination of stream fishing.

c. The substitution of lake fishing for stream fishing.

d. A change generally for the better in the stream fishing below the reservoir.

e. The provision of additional areas suitable for other forms of recreation such as swimming, boating and summer cottages.

The matter is illustrated by the question as to whether the construction of reservoirs as proposed will increase or decrease the hunting, recreational and fishing opportunities of residents of eastern Pennsylvania. The major yardsticks may be summarized as follows:

Hunting
Fishing
Recreation
  Summer Cottages
  Vacation Facilities
  Swimming
  Boating

The reservoirs which have been investigated are the following:

Cannonsville
Barryville
Godeffroy
Wallpack Bend including Flatbrook
Lehigh
Nescopeck
Tobyhanna
McMichaels

Based on their field investigations and their wide knowledge of similar situations, the U. S. Fish and Wildlife Service and Dr. Gabrielson indicate three important matters as bearing on the question as to whether or not the reservoirs will increase or decrease recreation, and hunting and fishing for sport for the average sportsman and his family as follows:

A. There is a greater need to provide more fishing in Pennsylvania than to provide more hunting. A lake or reservoir that provides good fishing will furnish recreation to a greater number of people than will a corresponding area of land for hunting.

B. Few sportsmen travel much over 50 miles to hunt and fish. Therefore, fishing waters located further than, say, 75 miles will have little effect on the average sportsman.

C. Non-resident hunting and fishing licenses are so costly as to preclude out-of-state hunting and fishing by many sportsmen.

Of interest are the numbers of different kinds of licenses issued to sportsmen in Pennsylvania during the fiscal year 1950-1951.

Resident Licenses

Hunting	801,948
Fishing	618,621

Non-resident Licenses

Hunting	26,001
Fishing	19,789

The Fish and Wildlife Service report that hunting facilities for sportsmen, in general, are relatively good in Pennsylvania. As regards three of the reservoirs in New York state proposed by Incodel, it is considered by the Fish and Wildlife Service that the Godeffroy Reservoir will not favor sportsmen because the loss of hunting and trapping facilities will be much greater than the improved fishing; that the Barryville Reservoir will cause little loss of hunting, but will increase fishing; and that the Cannonsville Reservoir will about offset moderately good hunting by moderately good fishing. An evaluation of the effect of the reservoirs on fishing and hunting in the areas to be flooded is briefly and approximately summarized in the following tabulation:

Fishing

Present Value

Poor	Godeffroy
Moderately Good	Nescopeck Barryville Cannonsville Wallpack Bend
Excellent	McMichaels Tobyhanna Lehigh

Post-Reservoir Value

Poor	Lehigh
Moderately Good	Nescopeck McMichaels Barryville
Excellent	Godeffroy Tobyhanna Cannonsville Wallpack Bend

Hunting

Present Value

Relatively Unimportant	Barryville
Moderately Good	Lehigh Cannonsville
Excellent	Nescopeck Godeffroy McMichaels Tobyhanna Wallpack Bend

Post-Reservoir Value

Not Very Good	Barryville Lehigh Cannonsville Nescopeck Godeffroy McMichaels Tobyhanna Wallpack Bend

Wherever there is good fishing in a stream below a proposed dam, this fishing can be preserved and sometimes improved by the release of stored water from the reservoir. Thus, the loss of existing trout water might be offset by the improvement of fishing facilities below a dam.

The foregoing, when judged by the greater need for fishing than hunting in Pennsylvania, indicates that the general effect of the proposed reservoirs for sportsmen within 50 to 75 miles and in the same state as the reservoir will be beneficial. As a partial offset to the decreased hunting facilities, the Fish and Wildlife Service recommend that marginal land be acquired for hunting. There will probably be a competition as between hunting and vacation occupation in such marginal strips. Not only should the marginal lands around the reservoirs be controlled, but there also should be reasonable effort to apply proper measures to minimize erosion so as to reduce the amount of silt which might be deposited in the reservoirs.

The use of the reservoirs for recreation, including summer cottages, vacations, boating, and swimming, is difficult to evaluate mainly because of the quite frequent and considerable drawing down of the water surface for stream flow regulation. For instance, the approximate extent to which the water surface will be lowered about once in 15 years for each of the reservoirs is illustrated as follows:

Reservoir	Draw Down in Feet Estimated to Occur about One in 15 Yrs.
Cannonsville	73
Barryville	None or little
Godeffroy	90
Wallpack Bend including Flatbrook:	
Without Water Supply	43
With Water Supply	60
Lehigh	120
Nescopeck	120
Tobyhanna	125
McMichaels	90

An intensive use of the reservoirs for recreation will affect the safety of the water for domestic consumption. A considerable recreational use will certainly make the raw water from the reservoirs unsafe. However, as water filtration and chlorination are needed in any event, a reasonable and controlled use of the reservoirs for recreation is permissible.

Because of the barrier to the use of lakes and reservoirs imposed by state lines, it is considered that reservoirs located in Pennsylvania will be considerably more useful and valuable to the people of the Commonwealth than reservoirs in New York state. Furthermore, the limit of travel to fishing waters of 50 to 75 miles means that many more sportsmen will be within negotiable distance from reservoirs in Pennsylvania than from reservoirs in New York state.

24. Commercial Fishing, including Shellfish

Commercial fishing in the Delaware River and Bay extends not only to those species of fish which spend part or all of their lives in the inland waters of the Middle Atlantic Coast, but also to shellfish such as oysters, clams and crabs. Among the commerical fish which spend part or all of their lives in fresh water are: shad, sturgeon, sea trout, eel, croakers, striped bass, alewives, porgies, black drum and flukes. Fishing of striped bass and others is also done for receational purposes.

The greatest percentage of the income derived by the commercial fisheries is presently contributed by shellfish. In the past, however, the catch of fish that migrate to and from the upper reaches of the Delaware River for spawning, and particularly of shad, constituted a large source of income for commercial fishermen. In 1897, about 15 mil-

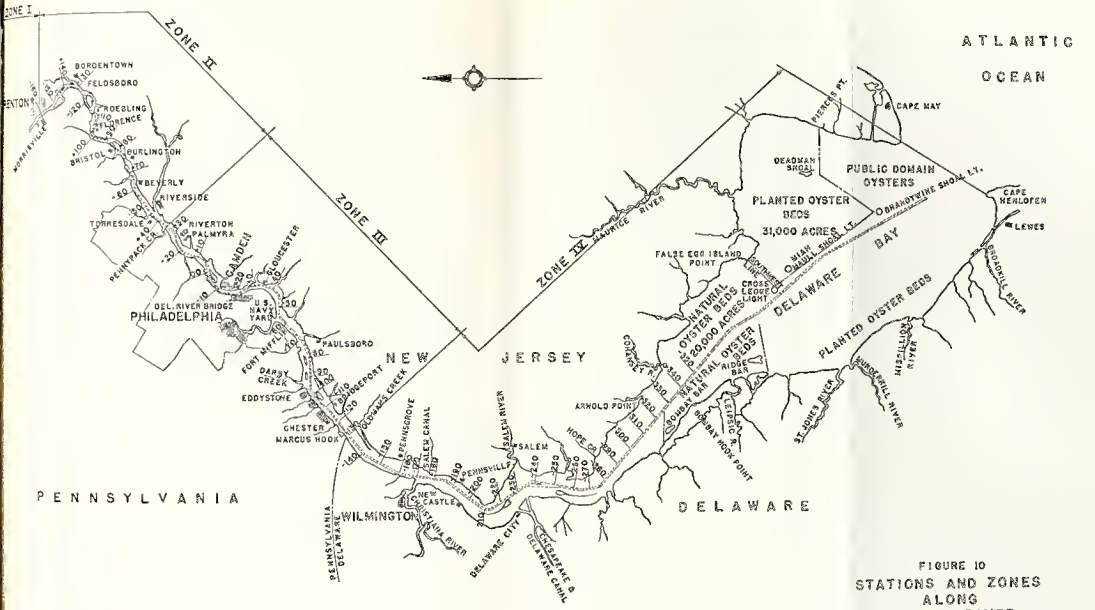


FIGURE 10
STATIONS AND ZONES
ALONG
DELAWARE RIVER
MORRISVILLE TO DELAWARE BAY
DECEMBER 1952

SCALE IN FEET
10,000 0 10,000 50,000

lion pounds of shad were caught in the Delaware River, as compared with about 70,000 pounds in 1950. The amount of shad fished from the waters along the Pennsylvania shore at the beginning of this century constituted about 17 per cent of the total shad catch in the river.

The causes of the decline of shad, as well as the other anadromous and catadromous fish, have been attributed to over-fishing and to pollution by sewage and industrial wastes. The possible construction of dams below the fertile spawning grounds of shad could also be deleterious to successful propagation, unless effective fish-ways are developed and installed.

A lethal barrier to the upstream migration of shad to their spawning grounds exists between Pennsville and Riverton, N. J. (see Figure 10), where the water was found to contain less than 5 p.p.m. of dissolved oxygen, according to a survey made by the Fish and Wildlife Service in 1946. This is the minimum dissolved oxygen that shad tolerate at the temperature of the water prevailing at the time of their upstream and downstream migrations. Furthermore, the concentration of dissolved oxygen in a stretch of some 35 miles was found to be less than 2 p.p.m. The concentration of ammonia was also found to be near the danger limit of 2.5 p.p.m.

Fish, like sea trout, croakers, porgies, black drum and flukes, which do not migrate further upstream than the Bay, should not be appreciably affected by changes in river conditions.

Oysters constitute the largest source of income to commercial shellfishing. They are grown in the Bay where the nature of the beds, the chlorinity of the water, the supply of food and the freedom from excessive pollution are favorable to their healthy growth. The chlorinity of the water in the natural beds located above False Egg Island should preferably be below 7,000 p.p.m. to prevent the incursion of oyster drills, which attack young oysters in particular, and cause greater damage to the oyster beds in Delaware Bay than any other enemy or pest.

One important fact that should be remembered is that the mean values of variables have little significance in biology. Animals live and die by reason of the extremes of their environment and not the means. Therefore, any plan that would tend to prevent extremes in river flow and river water quality should be beneficial to fish.

The table below shows the value of most of the commercial fish catch in 1949:

Fish	Value of Catch in 1949 (Dollars)
Oysters	$3,648,000
Clams	794,000
Crabs	415,000
Shad	4,000
Alewives	800
Croakers	11,000
Sea Trout	29,000
Striped Bass	67,000

The yearly harvest of oysters on the New Jersey side of Delaware Bay has been fairly stable in the past twelve years. It has not been as stable on the Delaware side because the local oyster industry was not closely controlled by state regulations until 1943 when the Delaware Commission of Shell Fisheries was created for the purpose of giving impetus to the oyster industry.

The yearly harvest of oysters, as well as that of the other shellfish, can undoubtedly be improved, but the direct benefit derived by Pennsylvania would be small, if any. However, if the shad and other fresh water fish runs were to be restored to their former status, the financial benefit derived by Pennsylvania would be quite material. It has been estimated that for shad alone, the potential yearly income of commercial fisheries in Pennsylvania could be as great as $390,000, as calculated on the basis of the catch in 1897 and the 1949 price of shad.

25: Agriculture

In the 1930 case before the Supreme Court, New Jersey contended that the proposed diversion by New York City would damage its agriculture. It was submitted that there were 3,650 acres of land in twenty-six tracts between Port Jervis and Trenton which, it was claimed, would be adversely affected as to agricultural productivity by the carrying out of the New York Plan. Some of the tracts were shown to be on islands on the Delaware River which belonged to New York. Testimony was presented by New Jersey in support of this allegation and in opposition by New York. The Master concluded as follows:

> *"On the whole I am quite content in the conclusion and finding that the carrying out of the New York Plan will have a very slight adverse effect on agriculture, and I think that such slight adverse effect will be very largely, if not entirely, overcome by the modification of the New York Plan as set out in this report."*

No statements relating to agriculture appear in

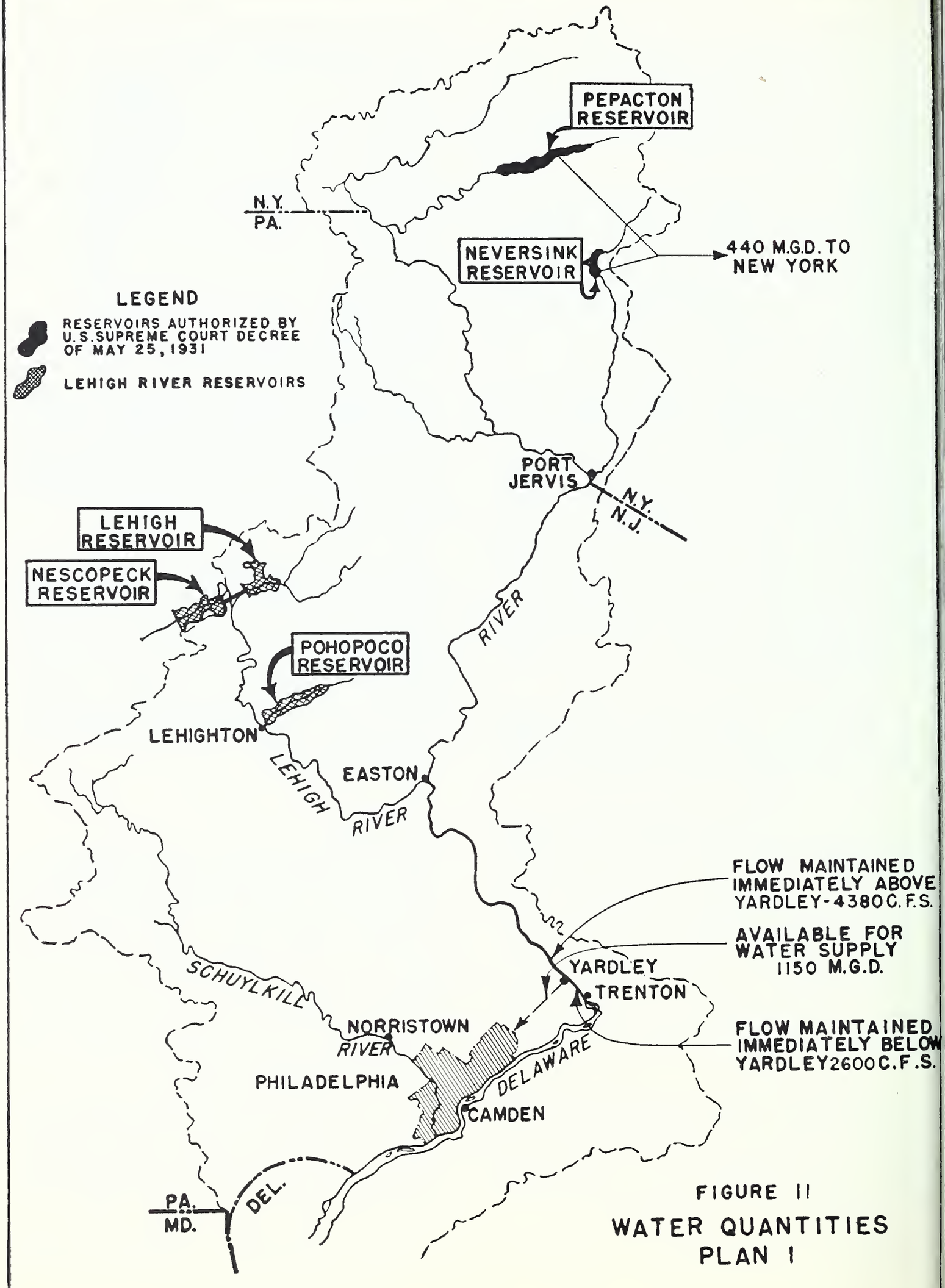


FIGURE 11

WATER QUANTITIES
PLAN 1

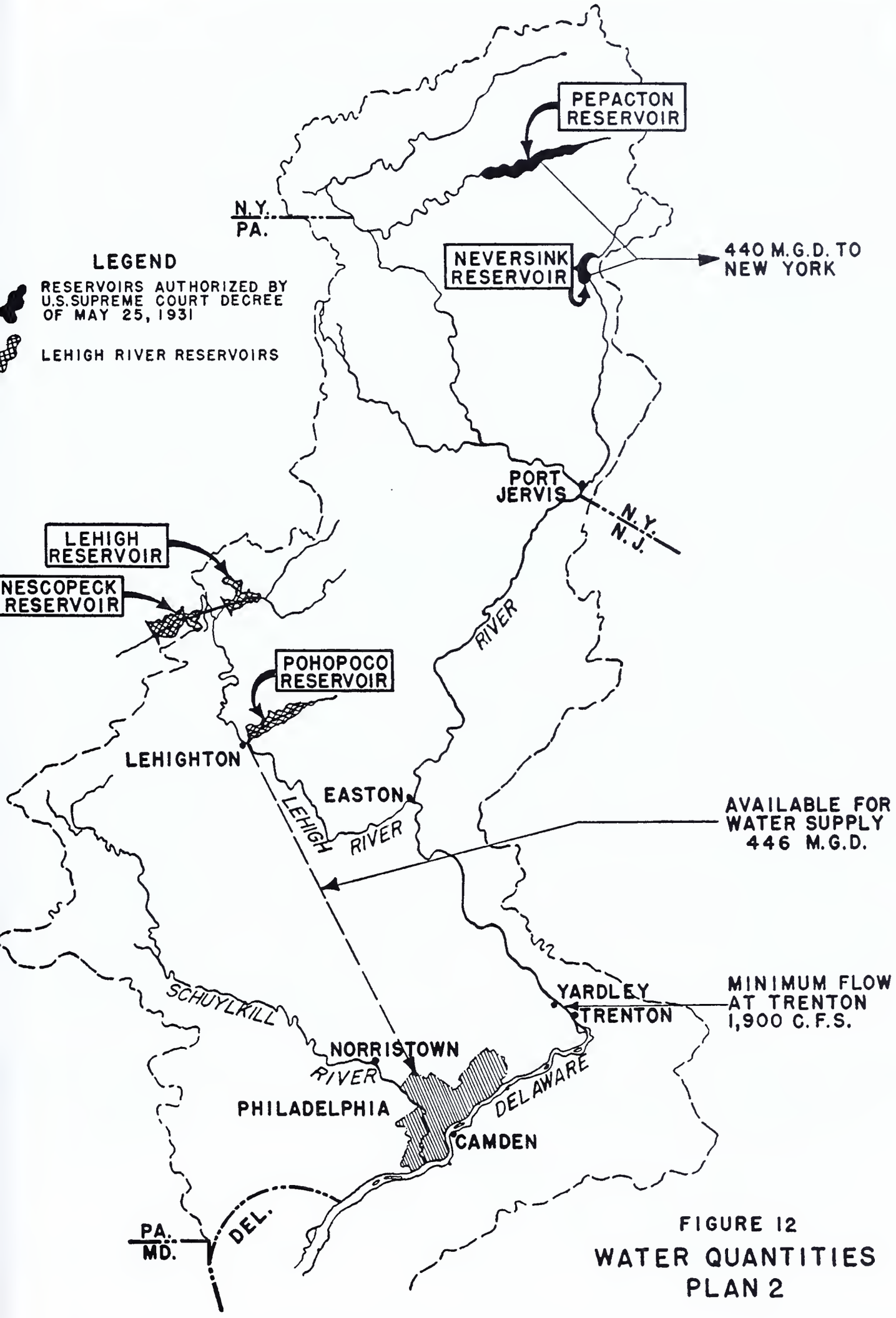


FIGURE 12
WATER QUANTITIES
PLAN 2

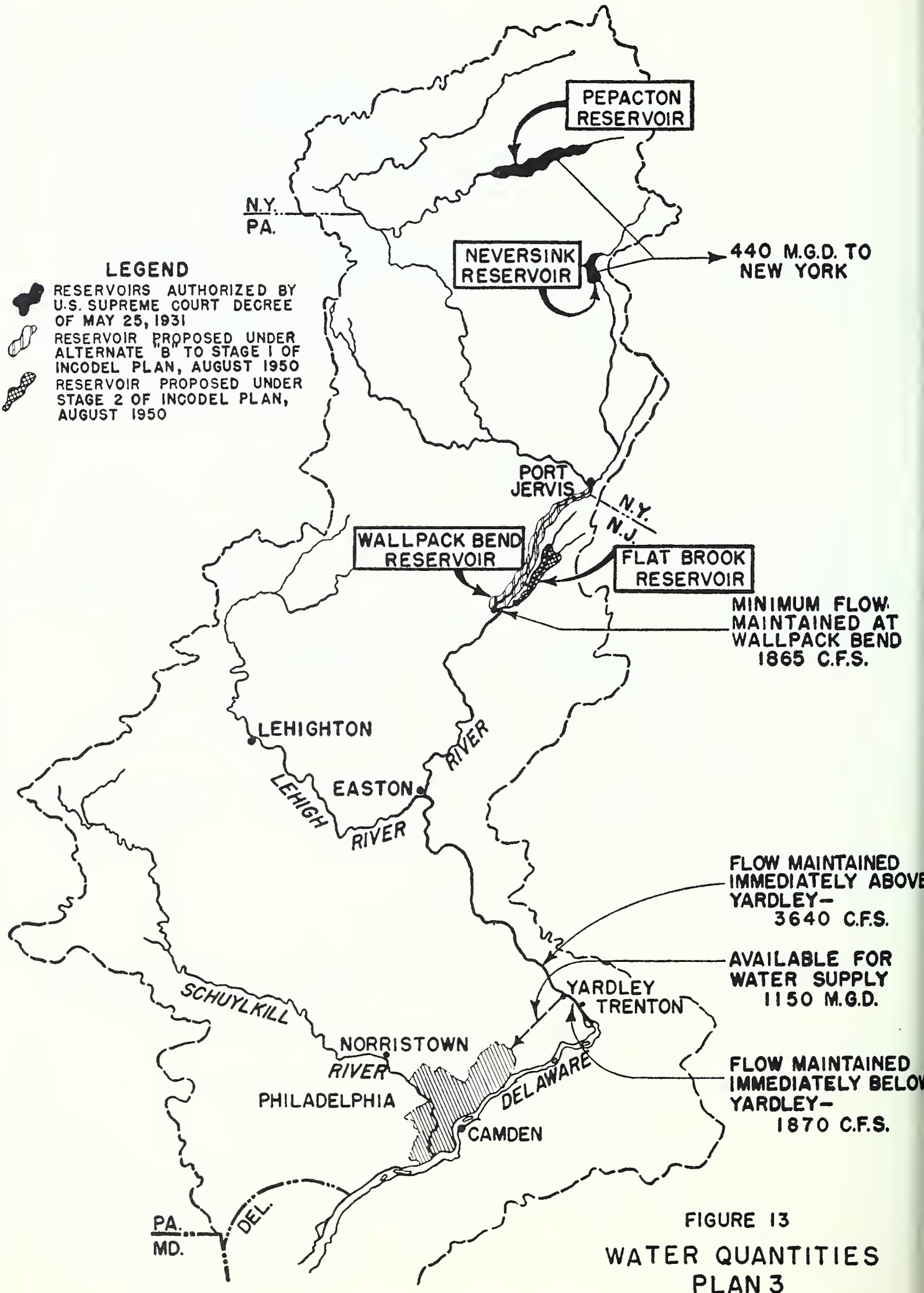


FIGURE 13

WATER QUANTITIES
PLAN 3

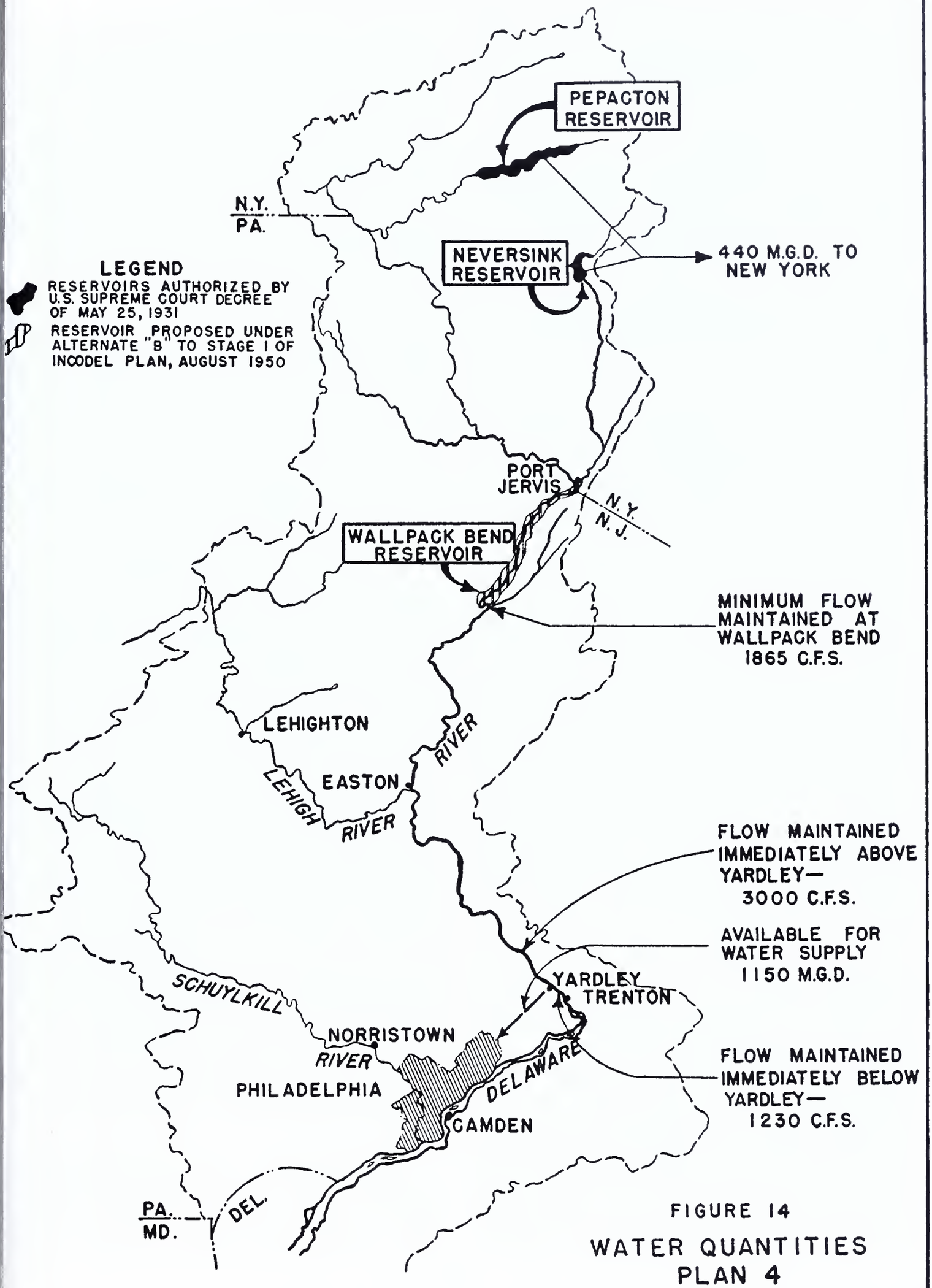


FIGURE 14

WATER QUANTITIES
PLAN 4

the Incodel Report of August, 1950. The matter does not seem to be important and no work on it has been done by the Engineers' Study Committee.

26. Project Illustrations

Some of the water supply projects which have been mentioned earlier in this report are illustrated on Figures 11 to 14, inclusive. Each of the illustrated projects includes the Neversink and Pepacton Reservoirs, now nearing completion, and assume that they would be operated in accordance with the Supreme Court of the United States decree of May 25, 1931, which authorized their construction, that is, a diversion of 440 m.g.d. would be made to New York City and that certain compensating releases would be made.

Figure 11 shows a plan under which the Lehigh-Nescopeck and Pohopoco Reservoir Projects would be constructed. It would be possible to make releases from these reservoirs on such a schedule that, during a repetition of the 1930-31-32 drought, a flow of 4,380 c.f.s. could be maintained in the Delaware River at Yardley. Thus, if the entire estimated future demand of the Philadelphia and southern New Jersey districts (1,150 m.g.d.) were diverted from an intake at Yardley, there would still be a flow not less than 2,600 c.f.s. in the river immediately below the intake. This is a substantial increase over the actual minimum flow of 1,220 c.f.s. that has been experienced in the Delaware River at Trenton.

Figure 12 shows a plan similar to the one shown on Figure 11, except that the water supply diversion would be made at the Lehigh River reservoirs and transported to Philadelphia through a tunnel or conduit, rather than at Yardley. Under such a plan, the water supply yield from the Lehigh-Nescopeck and Pohopoco Reservoirs would be only 446 m.g.d., not enough to meet the estimated future needs of the Philadelphia and southern New Jersey districts. The minimum flow that would be experienced at Trenton during a repetition of the 1930-31-32 drought, if the plan shown on Figure 12 were in operation, would be 1,900 c.f.s.

Figure 13 shows the distribution of the water resources of the Delaware River Basin that would be possible under a plan in which reservoir projects would be constructed on the Delaware River at Wallpack Bend and on Flat Brook. Although there is a very small drainage area tributary to Flat Brook Reservoir, the valley forms a large storage basin. Since the site is adjacent to the Delaware River, it is possible to divert flows from the Delaware River into Flat Brook Reservoir for temporary storage and subsequent release. Under the operation shown on Figure 13, the Pepacton and Neversink Reservoirs would be operated in accordance with the U. S. Supreme Court decree of May 1931 and releases would be made from the reservoirs at Wallpack Bend and Flat Brook on a schedule designed to maintain a uniform rate of low at a water supply intake at Yardley. The minimum release would be limited to 1,865 c.f.s., which is equivalent to 0.50 c.s.m. at the Wallpack Bend dam site. During a repetition of the 1930-31-32 drought, it would be possible to maintain a flow of 3,640 c.f.s. in the Delaware River at an intake located at Yardley. Thus, if 1,150 m.g.d. is diverted at Yardley for the purpose of serving the water supply requirements of the Philadelphia and southern New Jersey districts, the flow immediately below the intake would be maintained at 1,870 c.f.s.

Figure 14 shows a plan similar to the plan shown on Figure 13 except that only the Wallpack Bend reservoir would be constructed, in addition to the Neversink and Pepacton Reservoirs. The minimum release from the Wallpack Bend Reservoir would be limited to 1,865 c.f.s., which is equivalent to 0.50 c.s.m. at this site. The maximum flow that could be maintained in the Delaware River at a water supply intake at Yardley, during a repetition of the 1930-31-32 drought, would be 3,000 c.f.s. If 1,150 m.g.d. is diverted at the intake, the flow immediately below the intake would be maintained at 1,230 c.f.s.

It should be noted that all of these partial diversions from the Delaware River or tributary streams in Pennsylvania or New Jersey provide for the return of the water to the channel of the Delaware River at or below Philadelphia, and thus do not reduce the flow through the Chester-Marcus Hook area.

27. Acknowledgments

The assembly of the essential information for the preparation of this report would not have been possible without the wholehearted interest and fine cooperation of the many individuals, agencies and corporations who were approached during the investigation. The Engineers' Study Committee is pleased to express its appreciation for all such assistance. Mention by name of everyone who has rendered valuable aid is not attempted.

We are particularly indebted to Mr. Donald Jenks, Secretary of the Pennsylvania Water Resources Committee, for the splendid cooperation and assistance he has furnished throughout our studies.

Mr. James H. Allen, Executive Secretary of the Interstate Commission on the Delaware River, has made available to us records and other pertinent data in his files.

We consider the August, 1950, Incodel report prepared by Malcolm Pirnie Engineers and Albright and Friel, Inc., Consulting Engineers for the Commission, to be an outstanding contribution to the literature upon the Delaware River

Basin, and wish to express our appreciation to Messrs. Malcolm Pirnie, Ernest W. Whitlock, and Francis Friel for their cooperation in making available to us background data upon which that report was based.

Valuable data and assistance were furnished by numerous governmental and other agencies, including the following:

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The Pennsylvania Department of Forests and Waters, particularly Mr. R. J. Gillis, First Deputy Secretary, and Mr. W. E. Kirkpatrick, Secretary of the Water Power Resources Board.
The New Jersey State Department of Health.
The New Jersey State Department of Conservation and Economic Development, particularly Messrs. H. T. Critchlow, Director, and Dr. Thurlow C. Nelson, Chairman of the Division of Water Policy and Supply.

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Dr. L. Eugene Cronin, Marine Biologist, University of Delaware.

Dr. Austin H. Clark, Smithsonian Institution, Washington, D. C.

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Mr. H. M. Freeburn, Chief Engineer of the Philadelphia Suburban Water Company.

Mr. Joseph L. Reed, Superintendent of Water Filtration, Trenton, New Jersey.

Mr. Irving V. A. Huie, President, New York City Board of Water Supply.

Navigation Commission for the Delaware River and its Navigable Tributaries.

We also wish to acknowledge the cooperation of numerous industries in supplying us with data on their water usage and the variation in the quality of the Delaware River water. Among those supplying such data were the following:

Fairless Works of the U. S. Steel Corporation

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Atlantic Refining Company

Texas Company

Socony Vacuum Oil Company

Westinghouse Electric Corporation

E. I. duPont deNemours Company

Baldwin-Lima-Hamilton Corporation

Sun Ship Building Company

Eddystone Manufacturing Company

Scott Paper Company

Ford Motor Company

Sinclair Refining Company

American Viscose Corporation

Sun Oil Company

General Chemical Corporation

Deepwater Generating Company

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